A Cross-Linguistic Investigation of Reading Behaviour Between a Consistent and an Inconsistent Orthography: An Eye-Tracking Experiment

A thesis submitted for the degree of Doctor of Philosophy

by

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Reading Behaviour Between a Consistent and an Inconsistent Orthography

Abstract

According to the Simple View of Reading (SVR; Gough & Tunmer, 1986; Hoover & Gough, 1991), all variation in reading can be accounted for by two component skills; decoding and language comprehension. However, these skills also need to be considered in the context of orthography. Languages differ considerably in terms of their orthographic structure; inconsistent orthographies have an inconsistent grapheme-phoneme conversion, like that of English, and consistent orthographies consist of a consistent conversion, like that of Italian or Spanish. The Orthographic Depth Hypothesis (Katz & Frost, 1992) claims that efficient reading requires readers to adapt reading strategies to meet the demands of the orthography being read. Languages with varying depths of orthographies may require distinct reading strategies that drive the development of specific reading skills and may affect a bilingual's ability to efficiently comprehend texts in languages of varying orthographic depths. Further, inconsistent orthographies may place higher demands on word reading than consistent orthographies. According to the Hypothesis of Granularity and Transparency (Wydell & Butterworth, 1999), orthography can be broken down into two main features that may be responsible for incidences of phonological dyslexia; 'transparency' and 'granularity'. The HGT argues that transparent languages will yield fewer instances of phonological dyslexia than opaque orthographies. However, even in opaque orthographies, if the smallest graphemic unit representing sound is equal to a whole character or a whole word (i.e., coarse grain), as opposed to a syllable or phoneme (i.e., fine grain), it will not produce a high prevalence of phonological dyslexia. English dyslexics are known to have poor decoding skills, which may cause them to engage in compensatory eye-movement patterns during reading. The current experiment used eye-tracking techniques to compare reading strategies in three groups: native-English monolingual readers with and without developmental dyslexia (DD) and Spanish-English bilinguals reading in both their native and second language.

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1.1 Introduction to Reading and the Alphabetic Principle

Reading is a crucial skill, essential for academic success and participation in modern society. While the acquisition of oral language is a natural and automatic process (Chomsky, 1965) beginning at birth (Dehaene, 2009), the acquisition of reading is a slow, deliberate process that only becomes automatic as readers age and become more fluent. Most researchers in the field of reading would agree that the main goal of reading is to understand a text (e.g., Castles, Rastle & Nation, 2018). As Sprenger-Charolles (2004) pointed out, children may be able to understand a text that is read to them but may not be able to read the same text themselves. Therefore, an inability to read does not necessarily result from a failure to comprehend, but rather from a failure of some mechanism involved in the cognitive processing of the text. When children begin to learn to read, they already have a rich foundation of spoken language at their disposal including knowledge of word meanings. Thus, the challenge of learning to read begins with learning to associate arbitrary visual symbols with those meanings. The alphabetic principle is the understanding that those visual symbols represent sounds of the language.

Successful reading in an alphabetic orthography hinges on the complicated process of learning to convert abstract visual features (e.g., /-\) to visual symbols (graphemes e.g., A) to sounds (phonemes) that convey meaning (i.e., to decode words). In other words, readers must learn to understand the grapheme-to-phoneme correspondences (GPCs) of the writing system and be able to apply this knowledge as they read. As it turns out, acquiring these phonological decoding skills is not automatic or intuitive. Byrne and colleagues conducted a series of experiments on preschool children between the ages of 3 and 5 years to investigate whether children naturally learn the alphabetic principle (Byrne, 1992; Byrne &

Fielding-Barnsley, 1989, 1990; for a review, see Byrne, 2005). Children who hadn't yet learned letter names were taught to read aloud pairs of written words such as *fat* and *bat*. Following this, in a transfer task, children were presented with a new written word, such as *fun* and were asked whether the word was "fun" or "bun". The overwhelming majority of children in these experiments failed this transfer task which indicated to the researchers that children may not learn the alphabetic principle naturally.

So how do children learn these skills and master the alphabetic principle? The same study revealed that the children who were successful in the transfer task were the ones that had some prior training to be able to (1) segment phonemes in spoken words and identify initial phonemes and (2) recognize that there is a correspondence between letters in the transfer task and sounds (i.e., *b* and *f* in the example above; Byrne & Fielding- Barnsley, 1989) (for a review see Byrne, 2005). Indeed, there is a large body of research that has found that phonological awareness skills (i.e., the ability to identify and manipulate units of sound) are the most important predictors of reading outcomes (e.g., Adams, 1990; Schatschneider, Fletcher, Francis, Carlson, & Foorman, 2004; Share, Jorm, Maclean, & Matthews, 1984; Snow, Burns, & Griffin, 1998; Stanovich & West, 1989; Stuart & Coltheart, 1988) and these skills in pre-literate children can even predict reading outcomes before reading instruction has begun (Treiman, Hompluem, Gordon, Decker & Markson, 2016). For example, pre-literate children can begin to recognize rhyming words and count syllables (Treiman et al., 2016). Phonological awareness leads to phonological decoding ability, and once children are aware of these systematic patterns between graphemes and phonemes, learning becomes a reciprocal process whereby phonological awareness facilitates reading development which in turn boosts phonological awareness skills (Jorm & Share, 1983; Share, 1995). This reciprocal relationship, called the *self-teaching hypothesis*, provides a framework for how children become expert readers. This learning mechanism is also emphasized in models of word identification (i.e., Dual-route models: Coltheart, Curtis, Atkins, & Haller, 1993; Coltheart, Rastle, Perry, Langdon & Ziegler, 2001; Triangle connectionist models:

Seidenberg & McClelland, 1989; Plaut et al., 1999; Plaut, 1996; Harm & Seidenberg, 2004;) and is also present in skilled readers who continue to generalize patterns they have learned (e.g., Perfetti, Bell, & Delaney, 1988; Ziegler, Jacobs, & Klüppel, 2001). However, explicit instruction and training in phonological awareness skills is necessary and has been found to improve children's ability to read and spell (Ehri et al., 2001; Perfetti & Hart, 2002).

Thus, phonological awareness and phonological decoding play a central role in the development of word reading ability. Achieving this decoding ability is the core of reading, but is a complex developmental process suggested by some, to occur in stages or phases (e.g., Ehri, 1991; Frith, 1985; Gough & Hillinger, 1980; Marsh, Friedman, Welch, & Desberg, 1981; Chall, 1983) where learning begins with learning GPC patterns, and transitions into whole-word recognition processes for skilled readers. Research concerning literacy has made great strides in characterizing the cognitive processes involved in reading development and word recognition. Most current models of word recognition and reading (i.e., Dual-route models: Coltheart, Curtis, Atkins, & Haller, 1993; Coltheart, Rastle, Perry, Langdon & Ziegler, 2001; Triangle connectionist models: Seidenberg & McClleland, 1989; Plaut et al., 1999; Plaut, 1996; Harm & Seidenberg, 2004; and The SVR: Gough & Tunmer, 1986; Hoover & Gough, 1990) recognize the importance of phonological skills as a key foundation in the reading process.

As noted above, learning to read is contingent upon learning a language's print-to-sound mapping, and this mapping varies widely across alphabetic orthographies. There is now a growing body of evidence to suggest that reading processes are not all universal across all languages but may at least be partially driven by characteristics of each orthography. For instance, in English, there is not a one-to-one mapping between graphemes and phonemes (e.g., the word *please* has five letters, but only four phonemes p/l/ea/s). When GPCs do not have one-to-one mappings, the orthography is considered inconsistent. Orthographies with high one-to-one mappings such as Italian are considered to be consistent. Models such as the Orthographic Depth Hypothesis (ODH: Katz & Frost, 1992) and the Hypothesis of Granularity and Transparency (HGT: Wydell & Butterworth, 1999) converge on the idea that reading is affected by the consistency of print-to-sound correspondences in each language and Wydell and Butterworth (1999) further argue that prevalence of reading impairments such as developmental dyslexia may also be affected by the consistency of print-to-sound translations.

The overarching aim of the current thesis is to investigate word reading processes in normal and dyslexic readers of different orthographies, to further investigate these claims. The purpose of the current Chapter is to introduce topics relevant to the current thesis; including models that characterize the processes involved in typical development of word recognition and reading comprehension in English. The current Chapter will then review how these processes may differ across alphabetic orthographies and will further discuss how they may manifest in reading impairments, specifically in developmental dyslexia.

1.2 Models of Word Identification and the Role of Phonology in Alphabetic Languages

A key underlying foundation on which reading models are predicated upon in alphabetic languages is the importance of the process of mapping graphemes to phonemes. Children may be aware of a systematic pattern between letters and sounds and can transfer their own patterns from their knowledge of oral language before understanding the actual patterns. While examining children's writing, Read (1975) found that some of the younger pre-schoolers showed evidence of an invented spelling system, applying systematic phonological relationships, and even categorizing some phonemic segmentations. Interestingly, these patterns were applied consistently across their writing. These invented patterns were rooted in the conventions of oral language than written language, however these findings suggest that the development of decoding may be natural but must be explicitly directed for successful reading. Through explicit reading instruction, children eventually learn to recognize words holistically without the need to sequentially decode each phoneme-grapheme pattern every time a word is encountered (Seidenberg & McClelland, 1989; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001).

These early phonological awareness skills have been reported to be a strong predictor of later word-reading. For example, Muter, Hulme, Snowling & Stevenson (2004) conducted a 2-year longitudinal study of 90 British children beginning when they were 4 years old after just entering school. They measured phonological awareness skills (rhyme and phoneme detection and completion), letter knowledge, grammatical skills, and vocabulary as predictors of later word recognition (i.e., word-reading accuracy) and reading comprehension (i.e., word reading accuracy and comprehension questions). Results revealed that early measures of letter knowledge and phoneme sensitivity were strong and consistent predictors of later word recognition skills, while vocabulary knowledge and grammatical skills predicted reading comprehension. These results demonstrate that before one can comprehend a text, they must be able to efficiently identify words accurately, a skill that relies on phonological awareness (see Stuart & Coltheart (1988) for similar results).

Various models of word identification have been proposed over the past few decades such as the *Interactive-Activation Model* (McClelland & Rumelhart, 1981), *Activation-Verification Model* (Paap, Newsome, McDonald, & Schvaneveldt, 1982), *Multiple Read-Out* (Grainger & Jacobs, 1996), *Connectionist Dual-Process (CDP)* (Perry, Ziegler, & Zorzi, 2010; Perry et al., 2007; Zorzi, Houghton, & Butterworth, 1998), and the *Parallel Distributed Model (PDP)* (Harm & Seidenberg, 1999; Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McClelland, 1989). However, there are two main classes of models that have been the most influential in motivating research on reading; (1) Dual-Route Cascaded models (e.g., Coltheart, Curtis, Atkins, & Haller, 1993; Coltheart, Rastle, Perry, Langdon & Ziegler, 2001) which posit two distinct routes through which word pronunciation can be achieved. (2)

parallel distributed connectionist Triangle models (e.g., Seidenberg & McClleland, 1989; Plaut et al., 1999; Plaut, 1996; Harm & Seidenberg, 2004) which posit one forward-flowing connection between orthographic input and phonological output, and one semantically mediated connection. An overview of these models is provided below. It is beyond the scope of this Chapter to provide a comprehensive account of each of these models. Instead, the next sections will provide an overview of the basic structures of these models and discuss how they have been evaluated in the literature, and how they can account for reported findings on reading behaviour.

1.2.1 The Dual Route Models of Word Recognition

Dual-route models of reading, specifically the so-called Dual Route Cascaded Model of reading (DRC; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) assume two different pathways (or routes) for word pronunciation: a lexical (direct orthographic and indirect semantic) route and a sub-lexical (phonological decoding) route (see Figure 1). Prior to accessing these routes, pre-lexical processing occurs, where letters are initially identified by processing their abstract visual features and matching these to stored allographs. Following successful pre-lexical processing, readers have two routes available to convert print-to-sound. Reading via the lexical route is achieved through a direct connection between a written word form and it's orthographic representation in the lexicons (an internal word store). The lexical route is a dictionary "look-up" procedure and is the most efficient route for identifying familiar words but fails for unfamiliar words and nonwords that do not have stored lexical entries. Meaning can be accessed through interaction with the semantic system (sometimes referred to as the lexical-semantic route). Access to meaning is not considered critical for word identification, however it may be in guiding pronunciation of irregular words (e.g., *yacht* or *colonel*) and homophones (e.g., rows vs. rose) (Coltheart, 2006).

Reading via the sub-lexical route is achieved through serial decoding of grapheme-phoneme correspondences (GPCs). This route is often referred to as an "assembly" route as pronunciation is *assembled* one-by-one from left-to-right, using a language's linguistic rules that specify grapheme-phoneme correspondences. However, this route is restricted to regular GPC rules (i.e., when graphemes map directly onto corresponding phonemes). Thus, word identification for nonwords and unfamiliar regular words that follow English linguistic rules (e.g., *hint, mint*, and *lint*), is most efficient via the sub-lexical route, but will produce errors for irregular words (e.g., *pint* will be pronounced like *hint*; *colonel* would be pronounced like "colernel"; *yacht* "yatched"). In the latter instance, irregular words must be learned over time and their corresponding entry stored in the lexicons to be accessed via the lexical route (Coltheart et al., 2001).

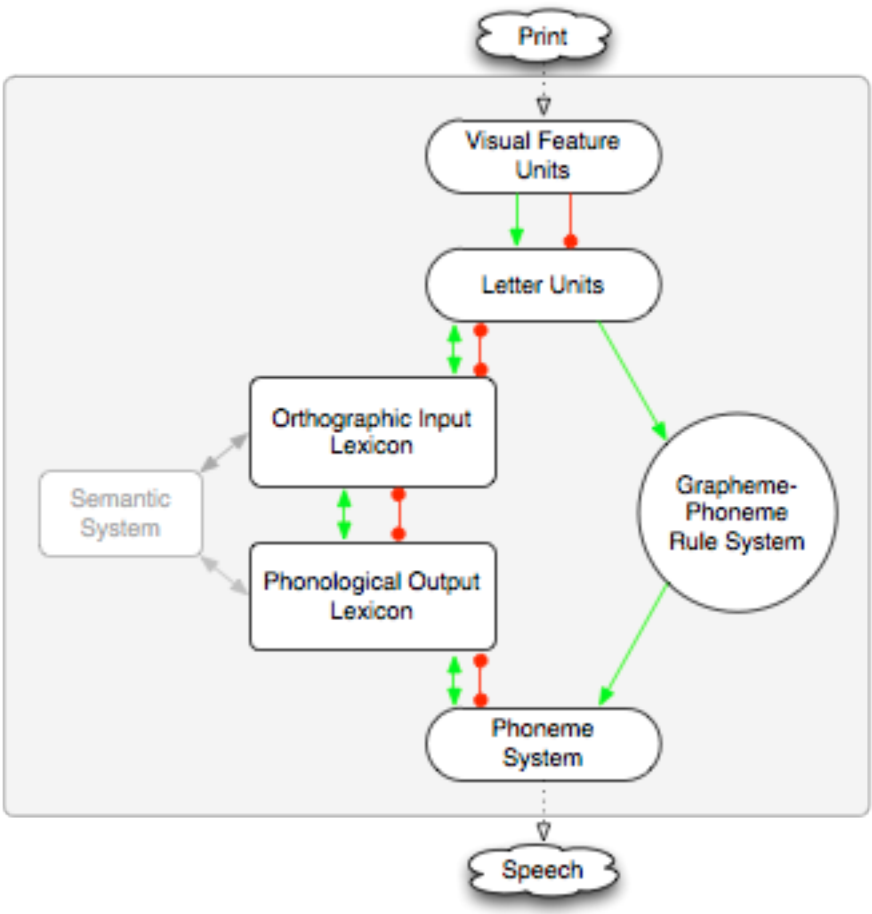

Figure 1. The DRC model (Coltheart et al., 2001)

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The DRC model has been computationally implemented (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) and was initially designed to explain common phenomena such as length and frequency effects in word and nonword reading from different reading tasks (e.g., lexical decision; reading aloud). In this model, both the lexical and sub-lexical routes operate in parallel to support successful word reading. The DRC can account for the typical findings of both word frequency effects and letter-string length effects found in English reading research. Frequency and length effects are observed when readers process high-frequency words faster and more accurately than low-frequency words (frequency effects; see Inhoff & Rayner, 1986; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) and process shorter letter-strings faster than longer letter-strings (see Weeks, 1997; Lowell & Morris, 2014 for more about length effects), respectively. According to Rastle and Coltheart (1998), frequency effects occur when the lexical route is activated quickly in response to high-frequency words which will likely be familiar to the reader and stored in the lexicon. When processing unfamiliar words or nonwords with regular GPCs, readers may be unable to retrieve a lexical representation, and the more laborious sub-lexical route must be used to map the graphemes to phonemes to determine pronunciation.

However, when a reader encounters a word that is both infrequent (or unfamiliar) and irregular, identification is slowed compared to frequent and regular words. Research has reported larger frequency effects for words with irregular pronunciations (e.g., words like pint, colonel, and yacht) compared to the pronunciation of regular words (Seidenberg, Waters, Barnes, & Tanenhaus, 1984). Thus, there is frequency x regularity interaction where words that are irregular and infrequent are read the slowest compared to frequent irregular, infrequent regular, or frequent regular words. Therefore, only low-frequency irregular words are likely to experience a conflict between lexical and sub-lexical pronunciations that requires resolution. For example, studies on proofreading tasks, where spelling errors are less likely to be detected in high-frequency compared to low-frequency words (Holbrook, 1978; White & Liversedge, 2004), and lexical decision latencies are faster for misspelled high-frequency compared to low-frequency words (Perea, Rosa, & Gómez, 2005).

Similarly, length effects occur when longer words are read more slowly than short words via the sub-lexical route. The size of the length effect is determined by the extent to which sub-lexical processing occurs (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). Length effects can also be caused by pre-lexical processing deficits where slower responses to longer words are a consequence of slow pre-lexical processing. The length effect is modulated by word-frequency because frequent words that are read via the lexical route may not demonstrate a length effect. Research typically reports a length x frequency interaction where word length affects naming latencies for low-frequency words and nonwords but not high-frequency words (Weekes, 1997).

Despite its support, the DRC has often been criticized as being a static (non-learning) model of skilled reading (e.g., Perry, Ziegler, & Zorzi, 2007; Seidenberg & Plaut, 2006; Snowling, Bryant, & Hulme, 1996), and historically has not addressed reading development until very recently (e.g., see ST-DRC Pritchard et al., 2018 for a DRC model of the self-teaching hypothesis). Seidenberg (2005) also points out that having both a rule-governed process and exceptions (irregular words) creates a paradox because many of the exceptions will overlap with the regulars, e.g., “PINT overlaps orthographically and phonologically with the regular word PINE” (p.238). However, it should be noted that Coltheart and colleagues (2001) addressed this and estimated that 80% of English monosyllables could be pronounced using only a small set of rules and the remaining 20% typically only had one grapheme deviate from a frequent pronunciation.

As an alternative, Seidenberg and colleagues proposed a word identification system that is not rule-governed, but *quasiregular* (Harm & Seidenberg, 1999, 2004; Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McClelland, 1989). In other words, there are different degrees of consistency in the mapping from grapheme-to-phoneme that range from rule-like regular mappings to more complex irregular mappings. Connectionist models that are based on this assumption will be discussed in the following section.

1.2.2 Connectionist Models of Word Recognition

Another class of models that have motivated much of the research involved in word identification, and especially, computational modelling of word identification, are Parallel Distributed Processing (PDP) models (Harm & Seidenberg, 1999, 2004; Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McClelland, 1989). PDP models attempt to model a variety of information processing tasks including reading. In contrast to DRC models which are modularly structured and sequential, PDP models argue that processing occurs in parallel across three systems; (1) visual system which, with respect to reading, mediates knowledge about orthographic word-form, (2) phonological system which is the internal representation of a word sound, and (3) the semantic system which deals with meaning. It is important to note that PDP models are not reading-specific, according to these models, these three systems underpin a variety of information processing tasks.

One well-known example of PDP models is the Triangle Model. The Triangle Model first proposed by Seidenberg and McClelland (1989) and further developed by Plaut and colleagues (Plaut, 1999; Plaut et al., 1996), purports that a word's pronunciation is a cognitive procedure generated via spreading activation through a network composed of groups, or layers, of processing units representing spelling (visual-orthographic input) and pronunciation (phonological output) of words. Triangle models identify three layers of processing units; the orthographic unit, the phonological unit, and the semantic unit (see Figure 2). Each layer is composed of sets of units that represent a large set of patterns. For example, the orthographic layer may be composed of letters or visual features of letters, while the phonological layer might be composed of phonemes or phonemic features (Seidenberg & McClelland, 1989).

Later iterations of this model added the third semantic unit (Harm & Seidenberg, 2004) to address the problem of reading comprehension rather than just pronunciation. The semantic unit activation is built up from both the phonological and orthographic units simultaneously in a “division of labour” fashion such that not one builds the semantic unit faster or better than the other (Harm & Seidenberg, 2004; Seidenberg, 2005). The semantic processing unit mediates comprehension between the orthographic and phonological units. Thus, the information a reader needs to identify a word is provided via a single set of input-to-output connections allowing access to all features of a word represented under each of the three processing units (orthographic, phonological, and semantic).

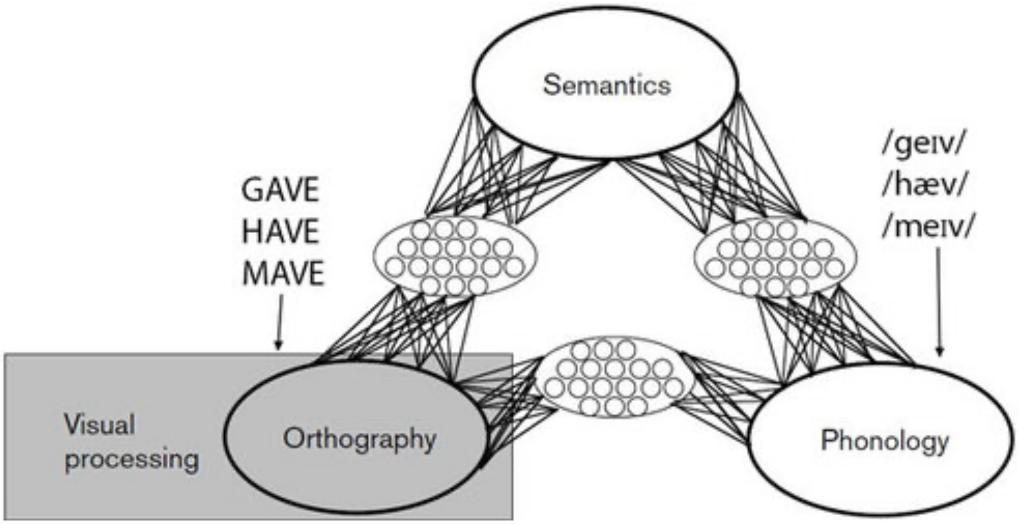

Figure 2. (Seidenberg & McClelland, 1989) connectionist "triangle" model of reading aloud.

In contrast to the DRC model, orthographic and phonological representations are not stored in the orthographic input lexicon and the phonological output lexicon as whole-word units. The model does not separate word and nonword reading, nor familiar word versus unfamiliar word reading. Instead, orthographic, and phonological features (e.g., letters or phonemes) are contained within their corresponding layers and patterns of these features are contained within the connections between the orthographic input and phonological output. Each connection, or *hidden layer*, is assigned a weight that modulates input to output flow of activation. Processing between these three systems is determined by the weights on connections between these systems that develop over learning. These weights are determined and adjusted based on learning orthographic and phonological features of different words and increased exposure. For example, learning the words *save* and *gate* will contribute to weight adjustments that aid in pronouncing the word *gave*. As depicted in Figure 2, all stimuli are thus processed with a graded division between two pathways either directly between vision (orthography) and phonology (V > P) or via semantics (V > S > P or S <> P). Distributed representations are those in which a given input (some stimulus such as a word, picture, or sound) corresponds to a pattern of activation over a fixed number of units across systems.

As readers learn orthographic patterns through increased exposure to words, the strength of the connections between vision and phonology (V > P) grows such that access to words becomes faster. Thus, connectionist models can also account for common phenomena of reading such as frequency and regularity effects. For example, since repeated exposure to words determines the strength of connections, the Triangle model predicts that frequent words will be pronounced faster than infrequent words (Forster & Chambers, 1973). For the same reason, nonwords will be processed slower than words because their pattern of activation across phonological units is unfamiliar. Similarly, since the connections are mediated by a triangulate of knowledge patterns across systems, regular words that have rule-governed and frequent orthographic-to-phonological mappings will be pronounced quickly and more accurately than irregular words (Seidenberg, Waters, Barnes, & Tanenhaus, 1984). Irregular infrequent words such as *pint* may never secure correct pronunciations because of conflicting activation from regular words such as *mint, lint* or *hint* (Patterson & Behrmann, 1997). The semantic mapping route is important for these types of words (V > S > P or S <> P) because they cannot be accessed through phonology alone.

Following this, the frequency x regularity interaction can also be explained by PDP models where low-frequency irregular words are expected to yield fewer exposures and patterns in the connections between orthographic and phonological units, thus, resulting in errors or reduced speed of activation. However, words with fewer competing representations either orthographically or phonologically should be processed faster regardless of their regularity. For example, Glushko (1979) found that when participants were presented with a word such as *gave*, which is rule-governed, but has the irregular neighbour *have*, participants were slower to read these words aloud than words that have no irregular neighbours such as *must*. These results can be explained within connectionist models. The same weights will be used in pronouncing all words, but exposure to the word *have* will shift weights away from optimal values for '*gave'* yielding a slower processing with less accuracy. Further, semantic connections also help to boost the correct pronunciation of these tupes of words. However, the word '*must'* has no competing irregular word and therefore will not generate similar processing delays. Similar effects are also found for nonwords such as *mave* (Seidenberg, 2005). These types of results are hard to explain under the DRC model, which would assume that both *have* and *must* should be processed at similar speeds via the lexical route since they are irregularly spelled words and would need to be stored in the lexicon.

PDP models have mainly been criticized on the basis that they are difficult to understand and are not intuitive (Seidenberg, 2005). In a similar vein, they have also been accused of being an implausible model due to the large amount of training that needs to go into the model to simulate skill (Pritchard, 2012; Norris, 2006). Finally, like any computational model of word identification including the DRC, it is fairly easy to falsify. For example, in an attempt to compare the ability of the DRC model with connectionist dual-process plus models (CDP+) Pritchard, Coltheart, Palethorpe and Castles (2012) found that although the DRC performed better at modelling nonword reading, both models failed to accurately match experimental data in reading performance from 45 English speakers reading aloud 412 nonwords.

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Though the DRC (Coltheart et al., 2001) and triangle models (Harm & Seidenberg, 1999; 2004; Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McClelland, 1989) are useful in conceptualising word-reading processes, their initial intent was to mainly capture the phenomena of skilled word identification, or the pronunciation of single words read in isolation in English. However, it is important to point out that these models of reading describe two key processes in word reading: one that involves translating spelling to sound to meaning and one that involve direct access to meaning from spelling without phonology.

However, the processes of acquiring reading skills and reading comprehension have not been tackled by these models. Reading comprehension is complex and involves not only the ability to pronounce written words, but to understand them in both isolation and in the context of sentences. The current Chapter will subsequently discuss models of reading development and specifically highlight models that also capture variance in reading comprehension.

1.3 Models of Reading Development

Children in English speaking countries such as the United Kingdom or the United States generally learn to read through a combination of formal academic instruction and informal practice at home. Reading development for native English-speaking children begins around age 5 and continues into adulthood (Teale & Sulzby, 1986; Koralek & Collins, 1997, Hiebert & Raphael, 1998). Beginning in the 1970’s, researchers began to propose that children learned to read via a sequence of stages. The main idea being that children or developing readers must pass through each stage to get to the next. Various theoretical stage models of reading have been proposed to illustrate the processes of reading acquisition (e.g., Chall, 1983; Ehri, 1991; Frith, 1985; Gough & Hillinger, 1980; Marsh, Friedman, Welch, & Desberg, 1981). A brief overview of these models is provided below.

1.3.1 Stage Models of Reading Development

Among the first to propose that reading developed in stages was Chall (1979; 1983), who suggested that children learn to read over a series of five stages. The first stage (0), termed the “pre-reading” stage, children begin to gain insights into the nature of words, letters, and sounds and begin to learn simple patterns such as rhyme or alliteration. At age six children begin to move through the next stage (1) where they learn that written letters are associated with spoken sounds. Knowledge of letters and their associated names as well as some fundamental decoding skills are gained during this stage. Next (2) around age seven, knowledge from the previous stage is consolidated and children begin the processes of confirming this knowledge with further reading practice. Here, children do not necessarily read to comprehend, but read to understand decoding and spelling patterns. In stage (3) around age 8, children begin to “read to learn” within a limited sing-goal scope until around age 14, stage (4), where they can begin to incorporate multiple points of view with increased complexity of language and ideas. Finally, around age 18, stage (5) is when readers can read longer texts with an increased degree of understanding and attention to detail and learn how to choose what to read based on individual goals.

Gough and Hillinger (1980) proposed a simpler two-stage model of learning to read. In the first stage (1), children are considered to be cue readers where paired associate learning is needed to achieve reading success. In other words, visual cues are needed to associate written words with sound and meaning in memory. In the second stage (2), children can utilize the alphabetic principle and learn to cypher, or decode, words. During this stage, children gain some knowledge of the grapheme-phoneme mappings can apply patterns they’ve learned to unfamiliar words. Cypher reading enables a process termed the self-teaching hypothesis whereby through phonological recoding, children can apply known patterns to a novel word and thus self-teach themselves a new orthographic word representation (Share & Jorm, 1987; Share, 1995).

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Marsh, Friedman, Welch and Desberg (1981) offered a four-stage theory of reading development. Similar to Gough and Hillinger's (1980) model, they proposed that the first stage (1), termed the "linguistic guessing stage" involves the use of visual cues to identify words. Next (2), the child enters a guessing stage where they are driven by a rote learning strategy to be able to make educated guesses to predict words from visual and linguistic cues. Following this stage (3), children enter the third stage where they learn to sequentially decode from left to right. Finally, children entering the final stage can use a hierarchical decoding strategy whereby they are able to decode words using higher order rules and analogies.

Frith (1985) published her three-stage model of reading acquisition where each stage represents the strategy a reader uses to read. Like the first stage in Gough and Hillinger's model (1980) and the first two stages in Marsh et al. (1981) model, she suggested that in the first stage (1), the "logographic stage", children learn to recognize words by using salient features such as graphic features to identify words. Next (2), readers enter the "alphabetic stage" where readers learn to read through grapheme-phoneme correspondences, here letter order is crucial, and graphemes are decoded sequentially. In the third stage (3), the "orthographic stage", Frith claims that readers have now acquired the skill to both apply grapheme-phoneme conversion rules to read and to recognise whole words.

Ehri (1987) argued that there is an intermediate phase between cue reading and deciphering. Termed the "phonetic cue reading phase", Ehri proposed that children will still use cues during this phase, but that cues do not necessarily need to be letters, and phonetic associations can also be made between printed words and their associated pronunciation in memory. Later, Ehri (1992) suggested a 4-phase model which detailed stages of reading based on "alphabetic" phases. (1) The Pre-alphabetic phase where children use visual cues and have little knowledge of GPCs. (2) The Partial alphabetic phase where children can use some component letters of words and their sounds, but they are unable to use a decoding strategy. (3) The Full alphabetic phase where children gain knowledge of decoding and GPCs. Finally, (4) the Consolidate alphabetic phase where repeated exposure to multi-letter patterns gives readers the skills to read like an adult.

While each of these stage models may serve as an informative theoretical framework, they have received criticism since their import. Stuart and Coltheart (1988) argued that not all children pass through the same sequence of stages, and that children might use different early reading strategies based on their phonological skill (those with good phonological skills will use these skills from the beginning and low-phonologically skilled children will treat reading as a visual task). In their longitudinal study, children's phonological skills were tested before they began to read at age four and then later as they were learning to read until they reached age eight. To test their reading skills, children were asked to read words aloud, and data was collected based on six types of substitution errors; (1) partial/irrelevant information used (e.g., target = play; error = sister), (2) letter segments used (e.g., target = school; error = home), (3) beginning letters used (e.g., target = cat; error = car), (4) final letters used (e.g., target = hat; error = cat), (5) beginning and final letters used (e.g., target = bird; error = bad), (6) target included in error (e.g., target = look; error = looks). Errors in groups 3 and 5 were considered to have a phonological element while the others were not. Results demonstrated that children who initially scored well on tasks continued to do so throughout the study and children who performed poorly continued to do so. Data from all children demonstrated that the patterns of substitution errors suggested that errors associated with phonological components (3 and 5) increased longitudinally while the others decreased, but with large individual differences in the error patterns. Stuart and Coltheart concluded that their results implied that children are not always progressing at the same rate through stages and are not passing sequentially through stages. Importantly, they argued that early phonological skills are crucial for reading progression and the development of graphemic parsing ability is necessary for an interactive relationship between phonological and orthographic analysis.

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Results from Stuart and Coltheart's (1988) study raised important considerations regarding the phonological processes involved in reading development. Although some stage models describe to some extent the importance of decoding skills, they fail to acknowledge individual differences among readers or make clear and testable hypotheses about reading development. In addition to the recognition of the importance of early phonological skills and decoding in reading (Stuart & Coltheart, 1988), Rapp, van den Broek, McMaster, Kendeou, and Espin (2007) advocated a need for models with clear testable hypotheses that develop enough of an understanding of the reading processes to allow for interventions for struggling readers. A current leading framework of reading comprehension that serves this purpose, is the so-called the SVR (SVR; Gough & Tunmer, 1986; Hoover & Gough, 1990).

1.3.2 The Simple View of Reading

The SVR was originally proposed by Gough and Tunmer in 1986, then later revised by Hoover and Gough (1990). The main premise of the SVR argues that reading comprehension (RC) is not the result of an additive combination of decoding (D) and language comprehension (LC), but rather the multiplicative combination of these two component skills; thus,

$$RC = D \times LC$$

Decoding skills are defined as "efficient word recognition" as well word pronunciations from letter-sound (grapheme-phoneme conversion) knowledge. Recently, Hoover and Tunmer (2018) further clarified that decoding is defined as word recognition accomplished through alphabetic coding, which refers to the relationship between written letters and sounds (grapheme-phoneme conversion) (Hoover & Tunmer, 2018). Language comprehension skills are defined as the ability to derive meaning from lexical information by employing the use of vocabulary, grammar, and semantic knowledge. It is important to note that language comprehension may also be referred to synonymously as 'oral language skills' or 'listening comprehension' across the literature, however the definition remains the same. The current thesis will henceforth refer to this construct as language comprehension.

The SVR was originally proposed to resolve an ongoing dispute about the role of decoding skills in reading comprehension, and whether they should be included in reading instruction. Some researchers (e.g., Fries, 1962; Gough, 1972; Rozin & Gleitman, 1977; Gough & Tunmer, 1986) argued that decoding skills were central to reading ability and that a phonics-based approach to reading should be an early goal of teaching. Others (e.g., Goodman, 1973), argued that learning to decode could hinder reading development and instead advocated for a 'whole language' approach where students should spend less time learning decoding skills and instead focus on learning word-meaning and contexts. The SVR can be viewed as an attempt to harmonize both of these approaches where decoding skills and 'whole language' or language comprehension skills are emphasized in the importance of reading development.

The SVR was proposed as a falsifiable theory and makes three key testable predictions. The first prediction states that the relative contributions of decoding and language comprehension to reading comprehension is best characterized by a product model, $RC = D \times LC$, rather than an additive equation, $RC = D + LC$. Hence, both skills will contribute to reading comprehension, but it is the interaction of these component skills that is more important than the contribution of both individually. In this model, both D and LC can range from 0 (complete inability) to 1 (perfect ability). Thus, in the case of a multiplicative model, if either of these variables is 0, then no matter how much skill there is in the other variable, there will still be 0 reading comprehension ability ($0 \times 1 = 0$). This assumption means then that a reader could have perfect decoding skills but fail to comprehend a text if they have no language comprehension skills, and vice versa. This can be conceptualized in an example of a foreign language learner of a consistent language (e.g., Spanish, or Italian) who may easily decode any given word because of the consistency of the grapheme-phoneme correspondences, but who cannot comprehend what was read. Another example of this is children with reading disabilities (e.g., dyslexia) who can understand a text when it is read to them, but do not have the strength of decoding abilities to read the text themselves. According to the SVR model, neither the decoding nor the language comprehension component is sufficient on its own; there must be some skill involving both components to successfully comprehend a text. The model thus predicts that neither of these abilities is impaired in skilled readers (Gough & Tunmer, 1968).

Second, since the relationship between decoding and language comprehension is multiplicative to explain variance in reading comprehension, it follows that for increasing levels of decoding skill, there should be a constant intercept value of 0 in a regression formula and positive slope values increasing in magnitude. For example, as discussed above, even at perfect skill in either decoding or language comprehension, if the other skill is absent, then there will still be zero reading comprehension. Thus, if decoding skill is perfect (D = 1) then the level of reading comprehension would only improve at the same rate as the level of language comprehension. The SVR argues that this pattern of linear relationships would not be appropriately represented in an additive model. An additive model would predict that intercept values instead increase from a floor of zero.

Third, the rate of improvement in reading comprehension due to improvement in language comprehension is not constant but is contingent upon an increase in decoding skill with slopes increasing in magnitude from a floor of zero. For example, for a reader with perfect decoding skills (D = 1) further improvement in reading comprehension would be identical to the improvement in language comprehension. However, for a reader with decoding skills that are only halfway perfect (D = 0.5), then for the same improvement in language comprehension as the former reader, improvement in reading comprehension will reflect only half the improvement as this reader will still only be able to read half of the material as the reader with perfect decoding skills. An additive model on the other hand would predict that improvement in reading comprehension would be identical to any improvement in either decoding or language comprehension regardless of the level of skill in the other component (i.e., positive, but constant slope values).

The SVR holds that a reader may fall into one of four quadrants based on the product value of their decoding and language comprehension skills (Figure 3). Readers are classified as either (1) an individual with good ability in both language comprehension and decoding skills (a skilled reader), (2) an individual with impaired decoding only, (3) an individual with impaired language comprehension only, or (4) an individual with both impaired decoding and language comprehension. Thus, the SRV argues that all reading difficulties derive from one of three conditions: poor decoding skills but adequate language comprehension, poor language comprehension skills but adequate decoding, or a combination of poor decoding and poor language comprehension skills. The most extreme cases of readers with severe decoding disabilities and poor phonological processing have been classified as dyslexic in English, and those with severe difficulties with language comprehension have been classified as having Specific Language Impairment (SLI). Individuals who have difficulties with both decoding and language comprehension but are not believed to have the same reading problems as dyslexics considered as having a “Garden Variety” reading disability (Hoover & Gough, 1990; Catts, Adolf, & Weismer, 2006). The SVR maintains that for less skilled readers, the relationship between decoding and language comprehension should be negative. It is important to note however, that the SVR does not claim to encompass all sources of dyslexia. Gough and Tunmer (1986) argue that poor decoding skills is simply a common denominator in dyslexic readers.

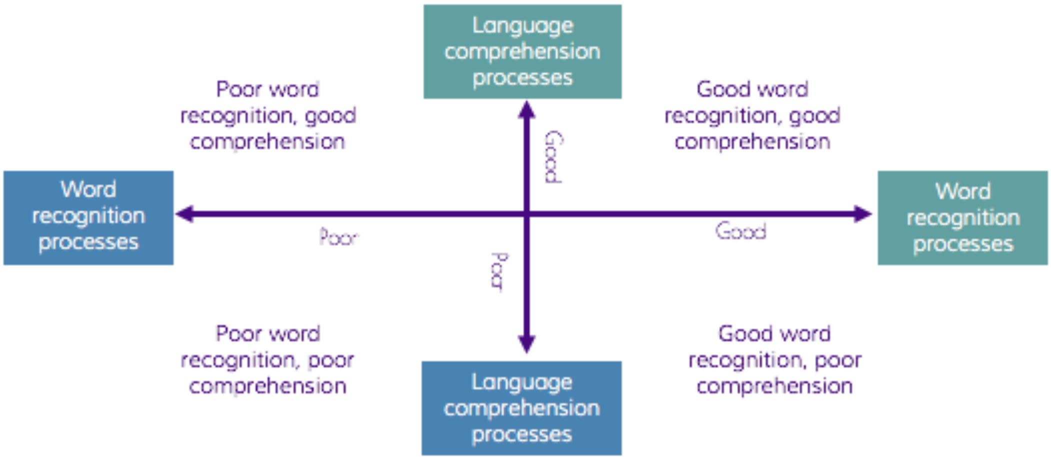

Figure 3. The Simple View of Reading (Gough & Tunmer, 1986) from Rose (2009)

The SVR has gained substantial empirical support across the literature and has been an effective model in predicting reading comprehension abilities and reading variation in native English speakers (Foorman, Koon, & Petscher, 2015; Catts et al., 2006; Hoover & Gough, 1990; Johnston & Kirby, 2006; Joshi & Aaron, 2000; Tilstra, McMaster, van den Broek, Kendeou, & Rapp, 2009). Initial support for the product model of the SVR came from the preliminary study conducted by Hoover and Gough (1990). This longitudinal study measured reading skills (i.e., nonword reading, listening comprehension, and reading comprehension) in 254 children across grades 1-4. Results revealed several key findings that supported the SVR model. First, a hierarchical regression revealed that the product model (RC= D x LC) could significantly account for an additional proportion of variance in reading comprehension after controlling for the additive model at each grade level. This result was further corroborated by the finding that none of the slope values representing the relationship between language comprehension and reading comprehension significantly differed from zero, implying that as the level of decoding skill increased, the relationship between language comprehension and reading comprehension remained constant. Second, decoding contributed more variance in reading comprehension than language comprehension in the earlier grades, but language comprehension contributed more than decoding in the older sample of children. These findings corroborated the assumptions of the SVR. However, it should be noted that findings from this initial study may be difficult to interpret as the participants were enrolled in an English/Spanish bilingual program and recruited from five different sites with varying reading instruction practices. Although the emphasis was placed on English reading with the goal of transitioning to English reading only, the students from this sample also learned to read in a second language (Spanish). Potential consequences from this type of sample will be further discussed in Chapter-4.

Longitudinally, the SVR can predict reading comprehension over the first four years of reading development (Catts et al., 2003; Hoover & Gough, 1990; Oakhill, Cain, & Bryant, 2003). The SVR formula can also be modified to predict the strength of each component skill given reading comprehension scores and one of the skill components. Catts, Adlof, and Weismer (2006) further tested the SVR model on three groups of students; those with normal decoding ability, but with poor reading comprehension skills, those with poor decoding skills, but with normal reading comprehension skills, and students who had both normal reading comprehension and decoding skills. The authors found that the SVR formula could be modified to, LC = D x RC (from RC = D x LC) and revealed that the SVR could accurately predict that strong decoding skills paired with poor reading comprehension will also exhibit poor language comprehension. Moving in the other direction however, poor decoding skills paired with normal reading comprehension skills may still yield normal abilities in language comprehension. One weakness of this study, however, is that they did not include a group with both poor decoding skills and poor language comprehension skills.

Research investigating the SVR has also revealed that the balance of influence of decoding and language comprehension shifts developmentally. For example, the role of decoding tends to decrease as children advance in reading skill, while the importance of language comprehension tends to increase (Oakhill et al., 2003; Tilstra et al., 2009). A recent meta-analysis of 100 studies by Garcia and Cain (2014) that represented a total of 42,891 readers ranging in age from 5 to 53 years found that as readers aged, the relationship between decoding and reading comprehension decreased. Specifically, the meta-analysis found that after age 10 correlations between reading comprehension and decoding decreased from a strong correlation range *rc* = .74 - .86 for the four youngest groups to a weaker correlations *rc* = .41 for the oldest. Language comprehension was found to be a moderator between decoding and reading comprehension, specifically higher language comprehension scores were associated with lower decoding-reading comprehension correlations. The SVR suggests that the relative influence of decoding and language comprehension shifts as reading becomes more proficient, such that decoding skills may be more influential for early-stage readers (i.e., non-skilled readers), while language comprehension abilities have more of an impact on reading comprehension in more skilled older readers of English. This assertion has been well supported in the literature (e.g., Curtis, 1980; Caravolas et al., 2019; Barnes & Kim, 2016; Goswami, 2002; Gough & Tunmer, 1986; Kendeou, Savage, & van den Broek, 2009). For example, Tilstra et al. (2009) sampled groups of students in Grades 4, 7, and 9 and found that the contribution of decoding to reading comprehension at Grade-4 accounted for 42% of the variance in reading comprehension, but only 13% for Grade-7 readers and 17% for Grade-9 readers. On the other hand, language comprehension accounted for only 19% of variance in reading comprehension in Grade-4, compared to the 35% for students in Grade-7, and 21% for students in Grade-9. The authors note that the difference between the proportions of explained variance in reading comprehension by both decoding and language comprehension were not statistically significant between the children in Grade-7 and Grade-9.

Using structural equation modelling, Kershaw and Schatschneider (2012) demonstrated that in Grade-7, both decoding and language comprehension uniquely and significantly predicted reading comprehension, but by Grade-10, decoding did not uniquely predict reading comprehension. This pattern has also been demonstrated longitudinally within the same sample (Catts, Herrera, Nielsen & Bridges, 2015; Catts, Hogan & Adlof, 2005; Muter, Hulme, Snowling & Stevenson, 2004). For instance, to explore early predictors of word recognition and reading comprehension, Muter et al. (2004) measured early phonological skills, letter knowledge, grammatical skills, and vocabulary knowledge at three different times over the course of 2 years in 90 British children beginning when they first entered school (M_{age} = 4 years 9 months). Word recognition skills were measured by asking children to read both regular (i.e., consistent GPC) and irregular words (i.e., inconsistent GPC). Reading comprehension was measured by asking children to read short narratives while their accuracy for pronunciation and correct answers to comprehension questions were measured. Results from path analyses revealed that letter knowledge and phoneme sensitivity measured at Time 1 and 2, consistently predicted later measures of word recognition at Time 2 and 3, respectively. On the other hand, measures of reading comprehension measured at Time 3, were best predicted by early word recognition skills measured at Time 2, vocabulary knowledge measured at Time 1, and grammatical skills measured at Time 2. These results demonstrate that early word recognition skills appear to be dependent on the development of phonological skills, however, reading comprehension skills depend less on phonological awareness skills and more on the development of higher-order language comprehension skills.

In a more recent longitudinal study, Catts et al. (2015) assessed decoding precursors (i.e., phonological awareness, letter knowledge, and rapid naming) and oral language abilities (i.e., vocabulary knowledge and The Test of Narrative Language (TNL; Gillam & Pearson, 2004)) at the beginning of kindergarten and later measured reading comprehension at Grade-2 and at the end of Grade-3. The authors used structural equation modelling and found that kindergarten decoding, and oral language skills predicted 49% of the variance in Grade-2 reading comprehension and 79% of the variance in Grade-3 reading comprehension. Specifically, kindergarten decoding skills (letter knowledge and phonological awareness) positively and significantly predicted Grade-2 word recognition, whereas oral language did not. However, kindergarten oral language skills did directly and significantly predict Grade-3 reading comprehension as did the measures of decoding. One main limitation of this study however is that some participants were bilingual. Although an English proficiency criterion was included, there is still ample evidence that bilingual reading patterns may be distinct from monolingual reading patterns (e.g., Verhoeven, 2000; Seymour, Aro, & Erskine, 2003; Wang, Koda & Perfetti, 2003). The sample of children also included both typically developing children and children who were identified by fluency measures as being at risk of reading disability. These group differences were not examined in this study despite substantial evidence that the reading process may be distinct for each of these groups (e.g., Gough & Tunmer 1986; Hoover & Gough, 1990; Coltheart, 2007; Plaut, 1999).

The current thesis is largely guided by the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990) as the driving framework to explore group differences in developed reading comprehension patterns between English monolingual readers with and without dyslexia and Spanish-English bilingual readers. The SVR was chosen specifically for its emphasis on decoding and for its key testable predictions concerning an encompassed view of reading comprehension and reading development across readers of all skill.

1.5 Reading Strategies Across Alphabetic Writing Systems and the Impact of Orthographic Depth

The models of word identification (e.g., the DRC and PDP models) and reading development (e.g., the SVR) described above are predominately driven by and tested in the English language. However, writing systems vary greatly across different languages, particularly in terms of how they use visual symbols to represent spoken language. Thus, there is a need to consider different languages within the context of these models to uncover both universal and language-specific aspects of reading.

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Some research has reported similarities across languages that would suggest there are universal reading processes. For example, in priming studies across languages findings generally indicate that recognition of a letter or character (e.g., in the case of Chinese or Japanese) precedes phonological activation which in turn precedes semantic activation (e.g., Chinese: Xu, Pollatsek & Potter 1999; English: Perfetti, Bell & Delaney 1988). However, it is generally assumed that reading is not entirely a universal process (see Verhoeven & Perfetti, 2017 for a review). Reading processes across languages may partially rely on specific characteristics of the spelling-systems in each language. Though it is beyond the scope of this thesis to discuss every difference between writing systems, the focus will be given specifically to differences in the consistency of the grapheme-phoneme conversions (GPCs) between alphabetic languages. The following sections will provide a brief overview of different types of alphabetic orthographies and the impact that GPC consistency may have on reading.

1.5.1 The Orthographic Depth Hypothesis

Orthographic depth refers to the consistency of the correspondence between orthographic units (e.g., graphemes), and phonological units (e.g., phonemes) and varies considerably across languages (Frost & Katz, 1987; Frost, Katz, & Bentin, 1987; Katz & Frost, 1992). Alphabetic orthographies can be classified by the degree of consistency of their GPCs. Deep (hereby *inconsistent*) orthographic texts such as English, have an inconsistent mapping of graphemes to phonemes, where several sounds may represent a single letter, and several letters or letter combinations may represent one sound (for example, the phoneme */f/* can be represented by the letter *"f"* as in the word *gift*, or the letter combination "ff" in ***cliff***, "lf" in ***calf***, "gh" in ***laugh***, or "*ph*" in *graph* In contrast, shallow (hereby *consistent*) orthographies such as that of Spanish, Italian, or Finnish, have a more consistent GPC mapping, where a given letter or character almost always represents just one sound with few exceptions (e.g., Perfetti & Dunlap, 2008; Ramirez, Chen, Geva, & Kiefer, 2010; Wydell, Vuorinen, Helenius & Salmelin, 2003). In general, inconsistent words are more difficult to read and spell than consistent words (e.g., Metsala, Stanovich, & Brown, 1998; Weekes, Castles, & Davies, 2006).

Given these structural differences between orthographies, the strategies that readers develop to comprehend a text may also differ depending on the consistency of that text's orthography. Cross-linguistic studies have been useful in detecting differences between reading behaviour in consistent vs. inconsistent orthographies. Specifically, research has reported larger frequency effects (Landerl, Wimmer & Frith, 1997; Rau, Moll, Snowling & Landerl, 2015) and lexicality effects (Paulesu et al., 2000), but smaller length effects (Ellis & Hooper, 2001; Goswami, Gombert, & Fraca de Barrera, 1998, Rau, Moll, Snowling & Landerl, 2015) for readers of inconsistent orthographies compared to readers of consistent orthographies. For example, readers of consistent orthographies, such as German, tend to show a smaller lexicality effect (i.e., respond to both words and nonwords with comparable speed and accuracy), while readers of inconsistent orthographies are slower and less accurate at pronouncing nonwords with accuracy scores as low as 40% for readers of English (Seymour, Aro, & Erskine, 2003). Aro and Wimmer (2003) compared numeral reading, number word reading, and pseudoword reading in English children in Grades 1-4 from six orthographies including; German, Dutch, Swedish, French, Spanish, and Finnish. By the end of Grade-1, all children except for English, read pseudowords, which also shared the letter patterns for onsets and rimes with the number words, with accuracy scores between 85% (for Finnish) and 90% (for Swedish). Readers of English scored significantly poorer in both reading speed and accuracy until they reached Grade-4.

Similarly, Goswami, Gombert, and deBarrera (1998) report that English and French (inconsistent orthographies) children showed a larger familiarity effect by responding to familiar words faster than unfamiliar words while Spanish (a consistent orthography) children showed no familiarity effect. Further, English readers also respond faster to orthographically similar nonwords (i.e., nonwords that have similar spelling to real words) (Frith, Wimmer, &

Landerl, 1998; Wimmer & Goswami, 1994), and nonwords that share a rhyme with a real word (Goswami, Gombert, & deBarrera, 1998) while readers of consistent orthographies showed comparable response times regardless of the type of nonword. Results from these studies demonstrate that readers of inconsistent orthographies benefit from drawing upon both orthographic and phonologically stored lexical knowledge from real words to process nonwords that are similarly spelled or pronounced, whereas readers of consistent orthographies don't need this information to aid in nonword identification.

Conversely, length effects tend to be larger for readers of consistent languages compared to inconsistent ones (Ellis & Hooper, 2001; Goswami, Gombert, & Fraca de Barrera, 1998, Rau, Moll, Snowling & Landerl, 2015). For example, German readers tend to read short words faster than long words regardless of frequency, compared to readers of English who show a much smaller difference in reading times between short and long words (Goswami, Gombert, & Fraca de Barrera, 1998, Rau, Moll, Snowling & Landerl, 2015). Length effects reflect the extent to which a phonemic decoding strategy is used versus using larger pieces of information to process a word, such as rimes. For example, a larger length effect indicates a greater use of phonemic decoding which slows word identification for longer words. Thus, the differences in length effects across orthographies may indicate that readers of consistent orthographies rely to a greater extent on phonemic decoding than readers of inconsistent orthographies. Ellis and Hooper (2001) found that word length determined 70% of reading latency in Welsh readers (a consistent orthography) but only 22% in English. Further, some research has demonstrated that length effects for readers of English may even disappear entirely when controlling for the number of orthographic neighbours that can be obtained by changing a single letter at any position (Weeks, 1997).

Researchers have proposed various theories to explain patterns of differential behavioural findings between orthographies. Namely, the ODH (Katz & Frost, 1992), the HGT (Wydell & Butterworth, 1999), and the Psycholinguistic Grain Size Theory (PGST; Ziegler & Goswami, 2005), have been particularly influential in motivating research in reading across orthographies. Each of these will be discussed in turn below.

The ODH (Katz & Frost, 1992) highlights two points; (1) consistent orthographies are more easily able to support a word recognition process that involves the language's phonology whereas inconsistent orthographies require readers to process printed words by referring to their morphology via the printed word's visual-orthographic structure; (2) prelexical phonology is more readily available in consistent orthographies because phonology is easily assembled through words – the easier it is to access prelexical phonology, the more likely it will be used for both pronunciation and lexical access. Frequency and lexicality effects are presumed to indicate the extent of the use of the lexical route which is presumed to be relied on more in inconsistent orthographies. Larger frequency effects (i.e., larger latencies in response times) occur in inconsistent orthographies because word reading is processed via the lexical route which will yield faster retrieval for frequent words compared to infrequent words. However, readers of a consistent orthography can successfully decode both frequent and infrequent words at the same rate via the sub-lexical route. On the other hand, length effects may also predict the use of the sub-lexical route which will be slower as a function of word length. However, length may not affect a lexical strategy, whereby whole-words are processed to the same degree, as a decoding strategy. Thus, these findings indicate that readers of inconsistent orthographies may be relying to a greater extent on the lexical route while readers of consistent orthographies can rely on the sub-lexical route for efficient reading because there is less competition between the routes since a wor's phonology is more easily available prelexically and can be used with fewer costs.

The ODH proposes both a strong and weak version of the hypothesis. In the strong interpretation, the ODH postulates that readers must adapt their reading strategies along two different routes that are dependent on the GPC consistency of the orthography being read. Word recognition in a consistent language is possible through sub-lexical GPC decoding strategy without use of the lexicon. However, in an inconsistent orthography, reading must be supported via a lexical procedure by using different kinds of lexical information (e.g., morphemic, semantic).

In a slightly different proposal, the weak version suggests that both these procedures (or routes) are available to all readers, but their uses are dependent on the demands of the orthography being read. Thus, readers of consistent orthographies are more likely to succeed in reading by means of alphabetic decoding strategies than readers of inconsistent orthographies who must process most words by accessing them from memory in the lexicon. As readers gain skill, their subsequent reading processes may begin to differ across orthographies as a result of their successes or failures with the lexical and sub-lexical reading strategies. Katz and Frost (1992) state that they support the weak hypothesis over the strong.

Support for the ODH originally came from the earlier work by Frost, Katz, and Benton (1987) who tested readers of three orthographies varying in orthographic consistency: Hebrew, English, and Serbo-Croatian. Participants were asked to respond to stimuli in a naming task and a lexical decision task where the words were manipulated for frequency (high vs low) and lexicality (words vs nonwords). The authors report that readers of Hebrew, the most inconsistent of the three orthographies, showed the greatest frequency effects compared to the moderate effect found in English, and the nonsignificant effect found in Serbo-Croatian (the most consistent of the three). Further, it was reported that readers of Hebrew and English were the only groups to respond slower and less accurately to nonwords compared to real words. These findings suggested that readers of the consistent Serbo-Croatian were able to access phonology directly making use of the sub-lexical route an efficient strategy for both words and nonwords, while readers of the inconsistent orthographies use visual orthographic codes for lexical access and the sub-lexical route for nonword reading which is inefficent.

In a second experiment, the authors also report a semantic priming effect (i.e., the finding that response times are faster when a prime-target pair are semantically related such as *DOCTOR-nurse* versus unrelated *TABLE-nurse*) in naming for the readers of Hebrew and English, but not for readers of Serbo-Croatian. Frost, Katz, and Benton (1987) attributed these effects to the fact that readers of consistent orthographies can bypass semantic information to derive phonology directly from print yielding comparable response times and accuracies for all stimuli regardless of lexicality, while readers of inconsistent orthographies must access printed words from their internal lexicon.

Though the DRC model (Coltheart, Rastle, Perry, Langdon & Ziegler, 2001) has predominantly been tested in English reading, it has also been implemented across a range of alphabetic languages differing in orthographic consistency including French (Ziegler, Perry, & Coltheart, 2003), German (Ziegler, Perry, & Coltheart, 2000), Greek (Kapnoula, Protopapas, Saunders, & Coltheart, 2017), Italian (Schmalz, Marinus, Coltheart, & Castles, 2015) and Spanish (Ardila & Cuetos, 2016). In general, results from these studies in other languages have demonstrated that the DRC model cannot account for the patterns of smaller regularity[1], lexicality, and frequency effects found in more consistent languages. Compared to readers of English, readers of consistent orthographies have a greater and faster use of the sub-lexical route to read words aloud. Thus, the DRC model needs to be adjusted to speed the sub-lexical route in more consistent orthographies (Ziegler, Perry, & Coltheart, 2003). For example, Ziegler, Perry and Coltheart (2003) investigated the regularity effect in French with data from a naming task and implemented a French version of the DRC. French has more regular letter-to-sound correspondences than English and as a result, findings form this experiment demonstrated a different pattern of word-regularity effects in French compared to English. Specifically, in English, regularity effects are found for low-frequency words, but not high-frequency words, whereas in French, this effect was

[1] Although Spanish is predominantly a consistent orthography with regular spelling-to-sound correspondences, there are a few exceptions, which are described in further detail in Chapter-4.

found for both low and high-frequency words. A simulation of the DRC model (as it is applied to English data) could not account for this pattern of findings in French. The data was only accurately captured by speeding up the sub-lexical route. Thus, the DRC model needs to be adjusted to speed the sub-lexical route in more consistent orthographies (Ziegler, Perry, & Coltheart, 2003).

It is important to note, that some researchers have argued that it is not the speed of the sub-lexical and lexical routes that affect word pronunciation in inconsistent orthographies, but rather it is the competing activation of the two routes (e.g., Katz & Frost, 1992). However, this was not built into the original architecture of the DRC model (Coltheart et al., 2001).

Despite a wide range of studies supporting the ODH, not all studies have reported the same patterns of results. For example, both word frequency and priming effects have been reported in consistent languages such as Croatian (Carello, Lukatela, & Turvey, 1988), Italian (e.g., de Luca, Borrelli, Judica, Spinelli, & Zoccolotti, 2002), Dutch (e.g., Martens & de Jong, 2006) and Spanish (Sebastián-Gallés, 1991). Word frequency effects have also been reported in Japanese syllabic Kana (Rastle, Havelka, Wydell, Coltheart & Besner, 2009). Such results are interpreted to imply the superiority of the weak version of the ODH, which suggests that both the lexical and sub-lexical procedures are available to readers of all orthographies.

1.5.2 Orthographic Grain Size Theories

Wydell and Butterworth (1999) later expanded on the ODH (Katz & Frost, 1992) and postulated the HGT. The HGT asserts that orthography (in both alphabetic and nonalphabetic languages) can be broken down into two dimensions; ‘transparency’ and ‘granularity’. Transparency is similar to Katz and Frost’s (1992) description of orthographic depth in that languages with a transparent (consistent) orthography have a consistent print-to-sound conversion. Granularity refers to the size of the smallest orthographic unit representing a sound. The HGT was originally proposed to account for the behavioural dissociation of AS, an English-Japanese bilingual who demonstrated high performance in Japanese reading, but very poor performance in English reading. Wydell and Butterwoth (1999) argued that phonological dyslexia would be rare in two conditions: (1) in transparent orthographies where the print-to-sound (e.g., GPCs for alphabetic languages) are one-to-one regardless of the level of translation of orthographic units to phonological units (i.e., at the phoneme, syllable level or whole-character level and (2) even in opaque orthographies, if the smallest graphemic unit representing sound is equal to a whole character or a whole word (i.e., coarse grain), as opposed to a syllable or phoneme (i.e., fine grain), it will not produce a high prevalence of phonological dyslexia.

Later, Ziegler and Goswami (2005) proposed the Psycholinguistic Grain Size Theory (PGST) arguing that early readers are confronted with three problems: availability, consistency, and granularity of spelling-to-sound mappings. Reading strategies depend on the efficiency with which these problems can be conquered by readers, which will vary across languages.

The availability problem refers to the fact that not all phonological units in a word are explicitly accessible prior to reading. Thus, connecting orthographic units to phonological units that are not yet readily available requires further cognitive development. The consistency problem is the same one outlined in the ODH (Katz & Frost, 1992) and the HGT (Wydell & Butterworth, 1999) which reflects the fact that orthographic units and phonological units do not always have a consistent correspondence. Some graphemes may be represented by multiple pronunciations and some phonemes may be represented by multiple spellings. Both types of inconsistencies are assumed to slow reading development. It is important to note however, that the major difference between the PGST and the HGT (Wydell & Butterworth, 1999) is that the PGST suggests that orthographic transparency is not predictive of a reduced incidence of developmental dyslexia. Finally, the granularity problem, which is also similar to the one outlined in the HGT (Wydell & Butterworth, 1999), refers to the fact that when a phonological system is based on smaller grain sizes (e.g., alphabetic languages), then there will be many more orthographic units to learn than for readers of a language whose phonological system is based on larger grains (e.g., Japanese Kanji).

The extent to which beginning readers face each of these problems determines the distinct reading strategies that will be developed to meet the demands of their orthography. According to the PGST framework, readers of inconsistent orthography may develop reading at a lower rate compared to consistent orthographies because of their need to develop reading strategies that allow them to process linguistic units of varying grain sizes. Children learning to read in consistent orthographies can rely on decoding processes at the smallest linguistic grain size of the phoneme which is sufficient for successful reading. However, this strategy is unreliable in inconsistent languages, therefore readers of those languages must develop reading strategies that process a variety of linguistic grain sizes, including small grain sizes at the phoneme level, and larger ones such as rimes and whole words. As a result, languages with inconsistent orthographies like that of English, may be more slowly acquired with frequent reading and spelling mistakes due to the increased demands of the inconsistencies of the orthography (Goswami, 2003).

The differences between length and frequency effects across orthographies is interpreted to reflect the use of either small grain or larger grain reading strategies. Larger length effects reported for readers of consistent orthographies compared to readers of inconsistent indicate a reliance on small unit decoding strategies, whereas readers of consistent orthographies may use larger grain size strategy which is not slowed by length. For the same reason, readers of consistent orthographies may use a small unit decoding strategy to process both high-frequency and low-frequency words at the same rate, whereas the larger unit strategy employed by readers of English is slowed by word frequency.

Convincing evidence that readers from consistent orthographies use different strategies to readers of inconsistent orthographies comes from a study by Ziegler et al. (2001) who compared reading of identical words (i.e., cognates) and nonwords between readers of English and readers of German. Participants were either native-German or native-English university students who were asked to read aloud lists of words and nonwords varying in length from 3 to 6 letters, and in the number of orthographic neighbours that share the same rhyme called body-Ns (e.g., *late, date, fate* are body-Ns of *hate*), while speed and accuracy were measured as dependent variables. Each list was identical between both groups of participants, and all were monosyllabic with regular grapheme-phoneme correspondences. Results showed that both groups of readers were highly accurate and thus accuracy was not analysed as a dependent variable. In terms of speed, both groups read shorter words faster than longer words (length effect), words with fewer orthographic neighbours with the same rhyme (body-Ns) were named more slowly than items with more orthographic neighbours, and real words were named faster than nonwords (lexicality effect). However, the length effect was larger for German readers than English readers, and the body-N effect was larger for English than German readers. These results were interpreted to indicate that German readers relied more on a small-unit decoding strategy while the English readers employed a larger-unit lexical strategy even when reading identical words. Although Germans were slightly slower at reading overall, this effect was not significant, further, both groups had a high level of reading accuracy indicating that each of these strategies supports efficient reading.

Taken together, the ODH (Katz & Frost, 1992), and orthographic grain size theories of reading (Wydell & Butterwoth, 1999; Ziegler & Goswami, 2005) are useful in accounting for differences in development, prevalence of reading disorders, and the use of reading strategies between consistent and inconsistent orthographies. For these reasons, these theoretical frameworks will drive the key predictions and goals of the current thesis.

1.5.3 Orthographic Depth and Reading Development Across Orthographies

Indeed, reading strategies appear to differ at least to some extent depending on the orthography being read, therefore it is reasonable to assume that the reading development to support different strategies would be different across orthographies as well. As previously discussed, inconsistent orthographies place a high demand on readers to rely on a largely constructed lexicon and lexical processing strategies to access phonology from orthographic units. As it turns out, these demands yield unique consequences on development that consistent orthographies do not encounter even at preliterate stages. For example, Cossu et al. (1988) compared the development of phonemic and syllabic awareness in preliterate Italian children (a consistent orthography) to preliterate children in English. Results from a tapping task (i.e., where participants were asked to identify the number of phonemes or syllables by tapping) demonstrated that the Italian children were more accurate at both phonemic and syllabic segmentation than English-speaking children.

Inconsistent orthographies like that of English also appear to be more slowly acquired in development than consistent orthographies with frequent reading and spelling mistakes due to the increased demands in reading development (Goswami, 2002; Firth, Wimmer & Landerl, 1998; Landerl, Wimmer & Firth, 1997). Compared to German (a consistent orthography) for instance, accuracy levels in English are lower and reading speed is slower even after three years of schooling (Firth et al., 1998; Landerl et al., 1997).

In a large-scale cross-linguistic study, Seymour, Aro, and Erskine (2003), compared children’s reading aloud of simple words and nonwords across 13 European languages. Results demonstrated the impact orthographic depth has on reading development. Seymour et al. (2003) found that English-speaking children in their first year of school had a significant delay in speed and accuracy in familiar word reading as well as nonword reading compared to children who were native speakers of other more consistent orthographies such as Finnish, Spanish, and Italian. Even when compared to other inconsistent orthographies such as French and Portuguese, English-speaking children showed a profound delay in simple decoding skills.

Goswami (2010) also reported that English-speaking kindergarteners were not able to identify as many phonemes in words compared to readers of other more consistent European languages including Greek, Italian and German. A subsequent regression analysis showed that a reading age of at least 7 years would be necessary before English readers matched readers of other European languages. Further, the strategies that readers of an inconsistent orthography use to decode are different from strategies used by readers of consistent orthographies. Ellis and Hooper (2001) compared children learning to read in English with children learning to read in Welsh (a consistent orthography). Results demonstrated that children who read Welsh efficiently relied on GPC decoding and could more accurately read passages aloud with fewer errors than English reading children who relied on whole-word strategies. However, readers of Welsh showed larger length effects than readers of English indicating a reliance on a sub-lexical decoding strategy. The whole-word reading strategies were demonstrated by the types of errors the English-speaking children made, such as whole word substitution errors.

The noted delay in decoding and overall reading development in inconsistent orthographies compared to consistent ones, has yielded reading instruction programs that spend a great deal of time and resources on instruction in phonics for beginning English readers (Ehri, et. Al., 2000). In consistent languages however, research has observed that children trained in phonics instruction do not differ in their achievement of letter-sound knowledge from children who were not trained in phonics instruction (Graaff, Bosman, Hassleman & Verhoeven, 2006).

Though readers of English may be slower to develop phonological awareness than readers of consistent orthographies, phonological awareness is still an important predictor of reading comprehension in consistent orthographies. For instance, Caravolas, Volin and Hulme

(2005) compared predictors in the development of reading and spelling in Czech (a consistent orthography) and English children. Phoneme deletion tasks and the spoonerisms task was used to assess phonemic awareness, which emerged as a unique predictor of reading speed, spelling, and reading comprehension. Phonemic awareness accounted for similar levels of variance in each of these outcome variables in both Czech and English indicating a similar predictive ability regardless of orthographic consistency. Further, there was no significant difference in phonemic awareness in the dyslexic participants from both languages, though they performed worse than the matched controls in their respective language. Studies in other orthographies have reported similar results such as in Spanish (Alegria, Pignot & Morais, 1982), Italian (Cossu, Shankweiler, Liberman, Katz & Tola, 1988), and Swedish (Lundberg, Olofsson & Wall, 1980).

It is important to note that not all processes of reading are dependent on aspects of orthography. Some processes of reading are found to be similar across several languages and different types of orthographies, while others appear to be language specific. Robust evidence of these processes are seen in neuroimaging studies where commonalities among neural activation during reading can be considered universal processes while dissociations in neural activation can be interpreted to represent a language-specific reading process. Though it is beyond the scope of this thesis to discuss all aspects of universality and language-specific processes in reading, some key neuroimaging studies are overviewed below.

Paulesu et al. (2000), investigated neural correlates of reading between university students with either a native consistent orthography (Italian), or an inconsistent orthography (English) using positron emission tomography (PET) scans. Participants were presented with three different types of word or nonword stimuli in their native language (1) real words (either in English for English reader or Italian for Italian readers) (2) nonwords derived from either English or Italian, (3) international words conforming either to Italian (e.g., pasta), or conforming to English (e.g., business). Results revealed that all participants read real words faster than nonwords (lexicality effect), but that the Italian participants read words, nonwords, and international words faster than the English participants even though the English words presented were as regular as possible (e.g., cabin, apron, and market). The behavioural data indicate that the reading strategy adopted by the Italian was sub-lexical GPC decoding strategy while this by the English was lexical strategy. Results from the PET scans showed that both English and Italian participants showed activation in the left frontal, temporal, and occipital lobes, demonstrating common universal aspects of reading. However, Italians showed greater activation in the left superior temporal regions (associated with sub-lexical processing) and English participants showed greater activations in both the left posterior inferior temporal gyrus and anterior inferior frontal gyrus (areas associated with word retrieval lexical processing). These results suggest a language-specific reading process where brain regions associated with sub-lexical processing strategies are activated during native reading in a consistent orthography while brain regions associated with lexical processing strategies are activated during native reading in an inconsistent orthography.

These effects can also be seen in developing readers as young as 8-years old. Chyl et al. (2021) compared print and speech activation localization in readers of Polish (a consistent orthography) with readers of English using functional magnetic resonance imaging (fMRI). Participants were presented with four different types of stimuli during the scanning session: (1) printed real words, (2) spoken real words, (3) printed symbol strings, and (4) noise-vocoded spoken words to minimize phonetic content. Participants also completed word-reading and nonword reading tasks. Behaviourally, participants were matched for reading, so they showed no difference in their word reading scores, however, behavioural results showed that Polish children read nonwords faster than English children. The fMRI data showed some aspects of language independent activation whereby several regions were activated for both groups for printed words (i.e., bilateral occipital, frontal, and temporal cortex) and for speech conditions (i.e., bilateral temporal and frontal cortex). Some aspects of language specificity were also found whereby English participants demonstrated greater activity in the left inferior temporal gyri than Polish in response to print. For speech, English had higher activation than Polish in the left fusiform gyri and the inferior temporal gyri, which are both associated with lexical-semantic processing in speech (Hickok and Poeppel 2007) and in print (Pugh et al., 2010), while left superior and middle temporal gyri was more involved in Polish than English both associated with phonological processing (Herman et al., 2013).

In sum, findings from these studies suggest that although there may be some universal processes in reading, and similar predictors of reading comprehension, they also highlight some of the key differences in reading between a consistent and an inconsistent orthography that are also predicated under models such as the ODH (Katz & Frost, 1992). Thus, when considering reading processes, the role of orthography must be considered from both a developmental perspective and a skilled word recognition perspective. From a developmental perspective, orthographic inconsistency may contribute to the prevalence of reading disabilities (e.g., Wydell & Butterworth, 1999). The next section will introduce developmental dyslexia in English with a particular focus on phonological and naming processes.

1.6 Introduction to Developmental Dyslexia in English

The above discusses how reading in both a consistent and an inconsistent orthography typically develops. However, not all readers demonstrate typical reading development. While most children can reach skilled reading levels through typical development, some children struggle to acquire the same skill. Developmental Dyslexia (DD) is a developmental reading disorder characterized by poor decoding, spelling, and impaired fluency, and accuracy in word recognition. DD affects approximately 10-12% of the English-speaking population, manifesting in beginning readers, but persisting into adulthood (Snowling, 2000). It is also important to note that DD contrasts with acquired dyslexia, which is associated with brain damage where reading was once unimpaired prior to an incident that caused the damage. Although DD has been extensively studied for over the past several decades and many definitions of DD have been offered (for a recent review see Snowing, Hulme & Nation, 2020), researchers continue to disagree on a universally accepted definition.

Researchers generally agree that DD is a neurological disorder with a genetic origin yet disagree as to the exact cognitive and neurological basis of the disorder. Thus, many definitions (e.g., see Lyon, Shaywitz, & Shaywitz, 2003; Rose, 2009), and hypotheses of the root causes of dyslexia have been proposed. Among the hypotheses of dyslexia, two have garnered the most attention from research and are relevant to this thesis; (1) a phonological deficit (Ramus, Rosen, Dakin, Day, Castellote, White, & Frith, 2003) and (2) a visual deficit (e.g., Hansen, Stein, Orde, Winter and Talcott, 2001; Stein, 2001; 2003). A more detailed discussion of these hypotheses will be offered in Chapter-3.

Although there is not a universally agreed upon definition, it is important for the purposes of the current thesis, to use a widely accepted and evidence-based definition of DD. Thus, the current thesis will adopt the Rose (2009) definition of DD. The United Kingdom has adopted the Rose (2009) definition of DD put forth in an evidence-based independent report. There are six essential parts to this definition; (1) DD is characterized by persistent difficulty in fluent and accurate word reading and spelling, (2) features of DD also include difficulties with phonological awareness, verbal memory, and verbal processing speed, (3) DD occurs across a range of intellectual abilities, (4) DD should be considered to exist along a continuum rather than having any clear cut-off points, (5) DD may co-occur with difficulties in motor coordination, mental calculation, concentration and personal organisation, but each of these should not be considered markers of dyslexia on their own, (6) a good indicator of the severity of DD may be determined by how an individual responds to intervention. This definition will be adopted for the current thesis as a framework for understanding DD, because it was coordinated and is the most widely used within the UK. Further, this definition was developed using the SVR as a foundational framework. That is, this definition advocates that DD primarily affects skills involved in word reading and fluency, which can be conceptualized in the decoding component of the SVR model. Although this definition has been criticized for being too broad (e.g., House of Commons, 2009), It is evidence-based and stems from a variety of extensive research on DD and informs diagnostic and intervention techniques. As such, this definition is useful in serving as a rough guide of consistent findings and areas of consensus across the literature. Although each criterion point in the Rose (2009) definition is important and highlights key characteristics of dyslexia, the first, second, and third criterion points are of particular relevance to the current thesis. Thus, these points will be discussed in further detail below.

1.6.1 Cognitive and Behavioural Correlates of Developmental Dyslexia in English

Researchers generally recognize the impact of several direct and indirect factors contributing to DD including genetic, environmental, behavioural, cognitive, and neurological (see Bishop & Snowling, 2004 for a review). For example, twin studies suggest a genetic aetiology of dyslexia (for a review see Scerri, & Schulte-Körne, 2010), and there appears to be a familiar link where children who have dyslexic parents are more likely to be at risk for dyslexia (e.g., Pennington & Olsen, 2010; Hulme, Nash, Gooch, Lervåg, & Snowling, 2015; Snowling & Melby-Lervåg, 2016). Thus, genes may play an interactive role in the expression of some of the cognitive difficulties that an individual with DD may experience. Further, parents who experience reading difficulties may subsequently provide an environment for their children that involves a lack of reading leading to a poorer reading experience for their children who may already be at higher risk of DD. Though the current thesis recognises that there are a variety of contributing and interacting factors to DD, it is beyond the scope of this thesis to review and investigate each of these factors. Instead, the current thesis will focus on cognitive and behavioural factors that can be observed in individuals with DD.

1.6.1.1 Deficits in Phonological Processes

Readers with DD are characterised as being slower and less accurate readers (e.g., Rose, 2009; Lyon, Shaywitz, & Shaywitz, 2003; Snowing, Hulme & Nation, 2020; Vellutino et al., 2004) compared to typically developing readers. The first two items in the Rose (2009) definition state that DD is characterized by persistent difficulty in fluent and accurate word reading and spelling, and include difficulties with phonological awareness, verbal memory, and verbal processing speed. These first two items address the relationship between slow and inaccurate reading with deficits in phonological processes, phonological representations, and deficits in phonological awareness, which has stemmed from a substantial amount of evidence from studies with dyslexic readers (for a review see Vellutino et al., 2004). For example, readers with dyslexia score poorer than typically developing readers on measures of phonological awareness such as blending sounds together to make words, identifying and isolating phonemes, segmenting words into individual sounds, identification of initial and final sounds in words or letter strings, and rhymes (e.g., Hulme, Bowyer-Crane, Carroll, Duff & Snowling, 2012; Melby-Lervåg, Lyster & Hulme, 2012; Share & Stanovich, 1995; Snowling, 1995; Snowling, Nation, Moxham, Gallagher & Frith, 1997). For example, the Spoonerisms task (Brooks & Walton, 1995) is a common way of assessing phonological awareness where participants are asked to exchange the beginning sounds of two words (e.g., ‘mystery house’ would become ‘hystery mouse’). Readers with dyslexia consistently take longer and are less accurate than typically developing readers on these tasks (e.g., Snowling et al., 1997; Snowling & Olson, 1992; Wolff & Lundberg, 2003). Phonological awareness leads to phonological decoding ability, and once children are aware of these systematic patterns between graphemes and phonemes, learning becomes a reciprocal process. Referred to as the Self-Teaching Hypothesis (Jorm & Share, 1983; Share, 1995) whereby phonological awareness facilitates reading development which in turn boosts phonological awareness skills. Children with deficits in phonological processing struggle to acquire this reciprocal learning mechanism. Although it is not the only marker of

DD, it appears as though it is a common factor among children with dyslexia. Specifically, children with dyslexia often demonstrate problems in phonological memory (Brady, Shankweiler, & Mann, 1983; Vellutino & Scanlon, 1982), and tasks associated with phonological processing such as nonword repetition tasks (Catts, 1986; Hulme & Snowling, 1992), and Rapid Automatized Naming (RAN) (Wagner et al., 1997). For example, readers with dyslexia also consistently perform worse than typically developing readers in both speed and accuracy on measures of sub-lexical processing such as nonword and word reading (e.g., Catts, 1986; Hulme & Snowling, 1992; Vellutino et al., 1991; 1994), which measures knowledge and application of grapheme-phoneme correspondence rules (i.e., phonological decoding).

As discussed, phonological ability plays a key role in reading and it is well established that phonological skills and phoneme awareness skills predict later word reading ability (e.g., Hoover & Gough, 1990; Muter, Hulme, Snowling & Stevenson, 2004; Scarborough, 1990, 1998; Stanovich, 1988; Wagner & Torgesen, 1987). Even pre-reading phonological awareness can predict later reading outcomes (e.g., Bryant, MacLean, Bradley & Crossland, 1990; Caravolas, Hulme & Snowling, 2001; Wagner, Torgesen & Rashotte, 1994) and deficits in phonological abilities have been established as the strongest predictor of poor reading comprehension (e.g., Bruck, M. 1992; Catts, et. Al., 2017; Snowling, Gallagher & Frith, 2003 Stahl & Murray, 1994). For example, in a recent longitudinal study, Catts et al. (2017) administered multiple measures of phonological awareness, oral language and rapid automatized naming to children at the beginning of kindergarten and then assessed multiple measures of word reading at the end of Grade-2. Structural equation modelling was used to identify children who had a deficit in phonological processing in kindergarten, and subsequently these children were found to be 5 times more likely to have dyslexia in Grade-2 than the children who did not show a deficit. This risk was even higher for students who also showed deficits in language comprehension and rapid naming.

Further, difficulties with phonological awareness and phonological abilities have been found to persist into adulthood (e.g., Gallagher, Laxon, Armstrong & Firth, 1996; Hatcher, Snowling & Griffiths, 2002; Snowling, 1980; Snowling, et. Al., 1997). For example, Snowling and colleagues (1997), assessed university students with dyslexia and compared them to age-matched typically developing readers from the same university. Participants completed a battery of tests that assessed phonological processing (i.e., rhyme production, phoneme deletion and spoonerisms), fluency (i.e., semantic fluency, phonemic fluency, digit naming, word and nonword repetition), and verbal short-term memory (i.e., digit span and nonword span). A measure of IQ was also administered using the Wechsler Adult Intelligence Scale-Revised (WAIS-R), which included a measure of vocabulary. Results showed that the dyslexic participants scored significantly worse than the typically developing readers on all measures of phonological processing and fluency but not on the measures of verbal short-term memory. Though participants did not have significantly different IQ scores, the dyslexic participants did score worse than the typically developing readers on the measure of vocabulary.

Similarly, Hatcher, Snowling and Griffiths (2002) compared a group of dyslexic university students with age-matched students without dyslexia. The participants were asked to complete a battery of tests to measure their IQ, reading, spelling, arithmetic, short term memory, phonological processing, verbal fluency, and speed of processing. Although the students with dyslexia performed as well as controls on measures of verbal and nonverbal IQ, they performed significantly worse on all tests of literacy, phonological processing, short term memory and processing speed. Some of the dyslexic students also showed slight impairments in arithmetic skills compared to controls. Thus, these studies demonstrate that even adult readers with dyslexia who attend university continue to show impairments on measures of phonological ability and reading compared to age-matched and education-matched students with similar IQ scores.

1.6.1.2 The Role of IQ

The third and fourth points in the Rose (2009) definition acknowledge relatively recent findings that dyslexia can occur across a range of intellectual abilities and should not be considered a dichotomous profile. Some researchers initially argued that dyslexia was a result of a discrepancy between observed reading ability, and one's potential for reading achievement, which was indicated by IQ scores. This diagnostic approach, referred to as the discrepancy model (Frankenberger & Fronzaglio, 1991) measures children's observed scores against what their predicted scores would be based on IQ levels. In these studies, a significant difference between observed reading scores and predicted reading scores yields a diagnosis of dyslexia.

However, Shaywitz, Fletcher, Holahan, and Shaywitz (1992) have demonstrated that diagnosing readers with dyslexia based on the discrepancy definition is not stable over the course of development. For example, as discussed in the previous section, adult readers with a history of dyslexia who attend university continue to show reading and phonological deficits despite having similar IQ scores to typically developing peers (e.g., Hatcher, Snowling & Griffiths, 2002; Snowling, 1980; Snowling, et. Al., 1997). Overall there is little evidence of differences in reading skills between those who met the criteria of a discrepancy and those who didn't, and the presence of a discrepancy has not been found to predict response to intervention (Cole et al., 1990; Plante, 1998; Francis et al., 2005; Stanovich, 1991; Stuebing et al., 2009). Thus, current definitions and assessment guidelines no longer use the discrepancy definition of diagnosing for dyslexia and recognise that any given reader with dyslexia may fall along any point along the IQ spectrum (e.g., Jones & Kindersley, 2013; Rose, 2009).

To summarise, DD is a multifaceted and complex disorder, with various contributing cognitive and behavioural factors including phonological awareness (Hulme, Bowyer-Crane, Carroll, Duff & Snowling, 2012; Melby-Lervåg, Lyster & Hulme, 2012; Share & Stanovich, 1995; Snowling, 1995; Snowling, Nation, Moxham, Gallagher & Frith, 1997), phonological memory (Brady, Shankweiler, & Mann, 1983; Vellutino & Scanlon, 1982), phonological decoding (Catts, 1986; Hulme & Snowling, 1992; Vellutino et al., 1991; 1994), and rapid automatized naming (e.g., Neuhaus, Foorman, Francis & Carlson, 2001; Wimmer & Mayringer, 2001; Windfuhr & Snowling, 2001), that must be recognized and acknowledged in a diagnosis of dyslexia (e.g., Jones & Kindersley, 2013). It is also important to note that there is an increasing awareness that dyslexia co-occurs with other disorders; in particular, many children with dyslexia have language impairments (McArthur et al., 2000), symptoms of inattention (Carroll et al., 2005), attention deficit hyperactivity disorder (McGrath et al., 2011) and problems of motor coordination (Rochelle and Talcott, 2006). However, it appears as though phonology plays a central role either as the expression of an underlying cause, or as a direct cause itself of DD. For this reason, the nature of phonological processing in typical readers and readers with DD warrants extensive investigation. This will be discussed further in Chapter-3 where a sample of dyslexic adult readers were tested on measures of word decoding, language comprehension, reading comprehension, and vocabulary and participated in a subsequent eye-tracking experiment to investigate objective reading strategies.

1.7 Chapter Summary

In summary, the current Chapter discussed the existing literature on the cognitive processes of skilled word reading as well as typical reading development in English and considered relevant theoretical framework that have been supported by research in characterizing this process. Following this, the current Chapter presented evidence that reading processes, specifically the processes of phonological decoding in word identification differ across orthographies and thus, models of reading that have been developed in English, may not be appropriate for all languages. Finally, the current Chapter presented an argument that deficits in phonological decoding and word reading may disproportionately affect readers of English due to the inconsistent nature of the English orthography.

1.7.1 Thesis Aim

The central aim of this thesis was to investigate these questions by measuring reading skills, and recording eye movement patterns exhibited by three different groups: English monolinguals with and without dyslexia and Spanish-English bilingual readers. Specifically, the current thesis aimed to answer 3 overarching research questions:

1.) What role do developed reading abilities and in particular, phonological decoding, play in reading comprehension across orthographies. It is known that reading is acquired faster for readers of consistent compared to inconsistent orthographies (Seymour et al, 2003). However, it remains unclear whether these initial gains in consistent orthographies lead to an advantage in later reading comprehension.

2.) What is the extent to which the SVR can account for the variance in reading comprehension for typical and dyslexic adult English monolingual readers, Spanish-English bilinguals reading in Spanish and Spanish-English bilinguals reading in English?

3.) How do reading strategies as indexed by eye movement patterns differ between typical and dyslexic adult English monolingual readers, Spanish-English bilinguals reading in Spanish and Spanish-English bilinguals reading in English and do these patterns reflect the extent of developmental differences between native readers of a consistent language (Spanish) versus an inconsistent language English?

1.8 Thesis Overview

To answer these overarching research questions, the current thesis consisted of four experimental Chapters each consisting of two experimental sections; (1) a behavioural Experiment where participants' reading skills including; language comprehension, vocabulary knowledge, decoding skills and reading comprehension were measured using offline reading assessments from the Woodcock-Munoz Language Survey III (WMLS III; Woodcock, Alcarado, & Ruef, 2017), and (2) An eye-tracking experiment where participants eye movements were tracked while they read sentences for meaning. Specific research questions are outlined in each Chapte with a brief overview provided below.

Chapter-2 (after the current introduction Chapter) measured the reading component skills comprising the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990) in adult monolingual English readers without reading impairments to investigate several ambiguities within the SVR model. This experiment was followed by a pilot experiment where participants' eye movements were tracked while they read sentences for meaning. Following the pilot experiment, a slightly adjusted eye-tracking paradigm was used to investigate the eye movement patterns involved in skilled reading in English. This Chapter served as the baseline experiment with which further comparisons were made with dyslexic readers and Spanish-English bilinguals reading in both Spanish and English.

Chapter-3 used the same protocols as in the first to measure reading component skills from the SVR and eye movement patterns in native English participants who have been diagnosed with dyslexia. These results were compared to results demonstrated in Chapter-2 by typical English monolingual readers.

In Chapter-4, the same protocols were used to measure and analyse reading component skills from the SVR using analogue measures from the WMLS III (Woodcock, Alcarado, & Ruef, 2017) and eye movement patterns from native Spanish-English bilinguals reading sentences in their native language (Spanish). Again, these results were compared to results demonstrated in Chapter-2 by typical English monolingual readers.

Finally, in Chapter-5, second language reading strategies were investigated. Specifically, this Chapter investigated the reading strategies of the same Spanish-English bilingual participants from Chapter-4 as they read in their second language (English). Thus, English reading abilities were measured via the WMLS III (Woodcock, Alcarado, & Ruef, 2017), and the bilingual participants completed the eye-tracking experiment in English. These results were then compared to results demonstrated in the second Chapter by typical English monolingual readers and results from the fourth Chapter by the same Spanish-English bilinguals reading in their native language.

Following these experimental Chapters, Chapter-6 concludes with a general discussion of the implications that were interpreted from all of the studies, as well as future directions for this line of research.

Chapter 2: Eye Movement Patterns and the Simple View of Reading in Native English Readers

2.1 Chapter 2 Overview

Reading is an important life skill and research continues to work to support a robust model of reading in English to advance our understanding. However, many models of word recognition and reading comprehension have been developed based on a substantial body of research conducted in English. A central question that remains, is whether these models can be applied to different groups of readers including typical readers, those with reading impairments, and second language readers and bilinguals. Before applying current theoretical frameworks to impaired reading and readers from different languages, it is important to demonstrate the way models function within skilled English monolingual readers without reading impairments.

Hence, the aims of the current Chapter were to (1) measure reading component skills named in The SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990), and (2) use eye-tracking to investigate eye movement patterns involved during skilled reading. This Chapter will serve as the baseline experiment with which future comparisons will be made with dyslexic English readers and Spanish-English bilinguals reading in both Spanish and English while also addressing some inconsistencies in the current body of literature.

This Chapter consists of two experiments; (1) a behavioural experiment where participants' reading skills including language comprehension, vocabulary knowledge, decoding skills and reading comprehension were measured using offline reading assessments from the Woodcock-Munoz Language Survey III (WMLS III; Woodcock, Alcarado, & Ruef, 2017), and

(2) an eye-tracking experiment where participants eye movements were tracked while they read sentences for meaning.

2.2 Experiment 1: The Simple View of Reading in an Inconsistent Orthography

2.2.1 An Introduction to The English Orthography

When learning to read, children must contend with basic characteristics of written English. English is an “irregular” language because grapheme-phoneme correspondences (GPCs) do not have a consistent one-to-one mapping (e.g., Foorman, Breier, & Fletcher, 2003). The English orthography is composed of 44 phonemes represented individually or in combination by the 26 letters of the alphabet (Lyon, 2009). There are 1120 ways of representing these 44 phonemes by using individual letters and letter combinations (graphemes). This yields a high level of inconsistent mapping of graphemes to phonemes, where several sounds may represent a single letter, and several different letters or letter combinations may represent one sound. For example, in English, the phoneme */f/* can be represented by the letter *“f”* as in the word *gift*, or the letter combination “ff” in ***cliff***, “lf” in ***calf***, “gh” in ***laugh***, or “*ph*” in *graph*. Moreover, English uses only five vowel letters to represent approximately 12–15 vowel sounds (Frost, 2005). These sounds are pronounced in many different ways depending on the vowel–vowel or consonant– vowel combinations (e.g., the ‘o’ has seven different sounds and 13 spelling forms as in load, hold, boil, toy, boot, short, cloud, own, not, ocean, robe, toe, owl, soup; Genessee, Geva, Dressler, & Kamil, 2006).

Inconsistencies can also be found between rimes, for example the words *hint* and *mint* are pronounced differently than the word *pint* though they have the same word rimes/ body, ‘int’. Orthographic consistency is related to regularity of GPC rules. Regular words that follow GPC rules for example *hint*, *mint*, and *lint* are more likely to be pronounced correctly compared to irregular words such as *pint* that do not follow GPC rules (e.g., Coltheart, 2006;

Perry, Ziegler & Coltheart, 2002). Thus, when children first begin to read, they are not only required to learn the sounds of the alphabet, but they also must learn sounds/phonemes from letter combinations that have become functional graphemes (e.g., *sh, th, ea).* These orthographic inconsistencies make the process of decoding difficult in English, as children must recode all these graphemes to their lexicon and learn the distinction between those that overlap. For example, the letter “h” overlaps with the grapheme “sh”, however the sound that the *h* makes in each grapheme is different. In this way, children must learn where to segment phonemes from a written word to correctly identify the word.

Further, changing phonemes results in a completely new word. For example, ***cat*** consists of three distinct phonemes (/k/, /æ/ and /t/), and replacing even one phoneme for another (/b/ for /k/) changes the word. Thus, phonological development must also include the ability to segment the initial sound of a word and the ability to isolate phonemic combinations. In fact, this phonological ability of segmentation is significantly correlated with letter-sound identification (Share, 2004). This finding indicates that benefits from the ability to identify GPCs may depend on the ability to isolate component sounds in a word.

These inconsistencies make the pronunciation of words in English unpredictable. Thus, beginning readers not only must develop phonological awareness to begin initial word-reading and decoding, but they must also generate a substantial exposure to a large vocabulary to become familiar with the orthographic structure of words (e.g., Perfetti & Hart, 2002). However, it may only take a few exposures for a word to be orthographically stored in memory (Share, 2004).

Although the inconsistent mapping of GPCs makes the phonology of English difficult to predict, it does sometimes serve as a semantic tool. On some occasions, there appear to be trade-offs between phonological information and morphological information (Perfetti & Harris, 2017). For example, some morphemes (i.e., the smallest units in language that still carry meaning but cannot be further divided) can be represented by several phonemes. The morpheme /ed/ attached to denoting the past tense, can be expressed by several phonemes: /t/ in worked; /d/ in closed; and /Id/ in waited. In these scenarios, morphology is preserved at the expense of phonology. Another example that highlights this phonological-morphological trade-off in English includes the use of a silent *g* in the word ***sign***. Although the letter *g* is not pronounced in the word ***sign***, the *g* reflects a meaningful connection to the word ***signature*** where the *g* is pronounced. Thus, the English orthography presents both semantic and phonological information simultaneously, forcing the reader to make distinctions between *sound* representations and *meaning* representations. These inconsistencies place a high demand on English word reading as the English orthography conveys multiple types of information simultaneously. Katz and Frost (1992) note that orthographic depth may reflect the relative priority a spelling system places on preserving morphology versus phonology. An inconsistent orthographic language often prioritizes morphology to make words more visually recognizable. In this case, children must also acquire morphological knowledge to effectively learn spelling to sound mappings, and this knowledge is thus associated with reading performance (e.g., Carlisle, 2000; Rastle, 2018; Singson, Mahony & Mann, 2000).

For the reasons outlined above, English is considered an inconsistent orthography which requires extensive experience to master (for a review see Perfetti & Harris, 2017). As detailed in Chapter-1, compared to readers of more consistent orthographies such as Italian or German, reading in English may develop at slower rate compared (e.g., Seymour, Aro & Erskine, 2003), with less accuracy (Goswami, 2002; Firth, Wimmer & Landerl, 1998; Landerl, Wimmer & Firth, 1997).

Since English is such an inconsistent orthography compared to other languages, it is important to evaluate current reading models in the context of skilled readers to examine the extent to which these inconsistencies may be apparent. The current Chapter will examine developed reading abilities defined in The SVR (Gough & Tunmer, 1986; Hoover & Gough,

1990) in skilled readers of the English orthography and use eye-tracking methodology to examine the profile of skilled reading. The results from these studies will be interpreted within the context of the processing consequences of the inconsistencies of the English orthography.

2.2.1.2 Skilled Reading in English

Most researchers agree that the goal of reading is to understand a text (e.g., Castles, Rastle & Nation, 2018), with the more skill and experience a reader acquires, the more efficient this process becomes. Skilled reading is distinct from both reading development (e.g., children) and impaired reading (e.g., dyslexia). Snow and Strucker (2000) define skilled reading as the "ability to read all or most of the words on a page, read words quickly, and use context cues only minimally for word recognition, which is primarily driven by using letters to access sounds" (p. 36).

Evidence that skilled reading is distinct from unskilled reading comes from neuroimaging data demonstrating reduced activation in ventral regions of the occipital temporal cortex located in the extrastriata cortex which encompasses both posterior fusiform gyrus and occipitotemporal sulcus. This area is where orthographic, phonological, and lexical-semantic features of a word are thought to shift into full-form lexical representations for skilled readers compared to less skilled readers (for a review see McCandliss, Cohen & Dehaene, 2003). In other words, it appears that novice readers use a procedure of reading that involves decoding words via assembled phonology while skilled readers are able to use an approach that involves whole-word processing. Because skilled readers use a whole-word approach when reading familiar words, length does not tend to have an impact on reading latencies (Weekes, 1997).

These processes are encompassed in DRC model (Coltheart, Rastle, Perry, Langdon & Ziegler, 2001), as discussed in Chapter-1. Although skilled readers can apply whole-word processes to read words with which they are familiar, evidence also indicates that skilled readers are able to generalise GPC patterns they have learned and apply them to novel and unfamiliar words, or even nonwords. This is demonstrated in studies investigating the pseudo homophone effect, or the finding that nonwords that can be pronounced like real words such as *feal* take longer to categorize as a nonword in a lexical decision task than other nonwords with no real word pronunciation such as *feep* even though they both only differ from the word *feel* by one letter (e.g., Perfetti, Bell, & Delaney, 1988; Ziegler, Jacobs, & Klüppel, 2001). Further, in semantic categorizations tasks, skilled readers are still slower and less accurate at categorising words with homophones such as *rows* compared to control words with no homophones (e.g., van Orden, 1987; for a review see Rastle & Brysbaert, 2006). Such results indicate that even skilled readers continue to apply systematic relationships between sounds and letters.

Since both a lexical whole-word approach and a sub-lexical decoding approach are used in skilled reading, it follows that the SVR model (Gough & Tunmer, 1986; Hoover & Gough, 1990), which predicates on the component skills involved in these processes, would apply to skilled readers. Though the SVR has been well supported in the literature there are still several areas of contention. The following section will address some of the ambiguities in the literature concerning the SVR and will thus provide a justification for applying this model to skilled readers of English.

2.2.2 Simple View of Reading Model and its Ambiguity

The SVR model (Gough & Tunmer, 1986; Hoover & Gough, 1990) states that a reader’s decoding skills (D) and language comprehension abilities (LC) are strong predictors of Reading Comprehension (RC). According to the SVR, decoding skills are defined as “efficient word recognition” (Hoover & Gough, 1990) as well word pronunciations from letter-sound (grapheme-phoneme conversion) knowledge (i.e., a sub-lexical reading skill) while language comprehension skills are defined as the ability to derive meaning from lexical information by employing the use of vocabulary, grammar, and semantic knowledge (Catts, Adlof, & Weismer, 2006).

The SVR has been widely supported by research examining English monolingual readers (e.g., Hoover & Gough, 1990; Sabatini, Sawaki, Shore, & Scarborough, 2010; MacArthur, Greenberg, Mellard & Sabatini, 2010; Vellutino, Tunmer, Jaccard & Chen, 2007; Barnes & Kim, 2016; Goswami, 2002) and has been found to be a good predictor of future performance in reading comprehension throughout the course of early development (Catts, Hogan & Fey, 2003; Oakhill, Cain & Bryant, 2003). The SVR has been useful in guiding investigations aimed at identifying and characterizing reading for different types of groups including bilingual children (Hoover & Gough, 1990), children with poor decoding or language comprehension skills (Catts et al., 2003; Hulme & Snowling, 1992; Hagtvet, 2003), typically developing children (Vellutino et al., 2007), and even adults (Savage & Wolforth, 2007). The SVR has also influenced the development of the reading curriculum (e.g., Rose, 2009).

Though there is extensive research examining the SVR, the current literature concerning the SVR still presents gaps that must be addressed. Two major contentions persist that are most relevant to the current thesis work. First it is unclear whether the product model, RC = D x LC or the additive model, RC = D + LC can best account for the variance in reading comprehension in a given sample. Second, the two main components described in the SVR, decoding and language comprehension, do not always account for the same proportion of variance across different studies within samples of the same skill level, and further do not seem to account for all the variance in reading comprehension. This observation has led to investigations into third component variables such as vocabulary knowledge, that may explain additional variance in reading above and beyond decoding and language comprehension such as vocabulary (e.g., Adolf, Catts, & Little, 2006; Braze, Tabor, Shankweiler, & Mencl. 2007; Cartwright, 2002; Johnson, Jenkins, & Jewell, 2005; Joshi &

Aaron, 2000; Tiu et al., 2003). The following sections will discuss each of these discrepancies in turn.

2.2.2.1 The Product Model vs. the Additive Model of the Simple View

As described above, one inconsistency regarding the SVR is whether the product model (RC = D x LC) or the additive model (RC = D + LC) can better account for variances in reading. Each of these models reflect distinct relationships between each of the three components i.e., decoding, language comprehension and reading comprehension. As previously discussed a key assumption of the SVR is that the relative contributions of decoding and language comprehension to reading comprehension is best characterized by a product model (RC = D x LC), rather than an additive equation, (RC = D + LC). In other words, the SVR model holds that neither decoding nor language comprehension on its own is sufficient for reading, there must be at least *some* skill from both components to successfully comprehend a text. In this model, both decoding and language comprehension can range from 0 (complete inability) to 1 (perfect ability).

On the other hand, an additive model of the SVR (RC = D + LC) would suggest that both components are sufficient on their own, and that a reader does not necessarily need *both* component skills to comprehend a text (Dreyer & Katz, 1992). Thus, successful comprehension of a text could still occur even if either decoding or language comprehension were completely absent (Gough & Tunmer, 1986; Hoover & Gough, 1990; Savage & Wolforth, 2007). However, the SVR posits that this model should not characterize reading comprehension. Since the initial publication of the SVR, several studies have indeed found the product model of the SVR to be more effective than the additive model in predicting reading comprehension (Carver & David, 2001; Hoover & Gough, 1990; Joshi & Aaron, 2000). In contrast, however, several studies suggested the opposite (Dreyer & Katz, 1992; Chen & Vellutino, 1997; Neuhaus et al., 2006).

Reading Behaviour Between a Consistent and an Inconsistent Orthography

As previously discussed, initial support for the product model of the SVR came from the preliminary study conducted by Hoover and Gough (1990). The longitudinal study measured reading skills (i.e., nonword reading, listening comprehension, and reading comprehension) in 254 children from Grades-1 to 4. A hierarchical regression revealed that the product model (RC = D x LC) could significantly account for an additional proportion of variance in reading comprehension after controlling for the additive model at every Grade level. The additional proportions of variance (i.e., ΔR^2) ranged from the lowest of 0.01 in Grade-1 to the highest of 0.07 at Grade-3. However, it is important to note that the participants in this experiment were English-Spanish bilinguals receiving reading instruction in *both* English and Spanish. Participants such as these may have developed distinct reading abilities compared to their monolingual peers, and thus results may differ between groups of bilinguals and monolinguals. Conners (2009) suggested that the bilingual nature of the sample may have yielded more readers with a score of zero in one of the component measures and thus increased the strength of the contribution of the product term (of language comprehension and decoding) than would be seen in a sample of monolinguals.

On the other hand, several studies have shown that an additive model accounts for significantly more of the variance in reading comprehension than a product model. Dryer and Katz (1992) were among the first to find greater support for the predictive ability of the additive model over the product model in explaining variance in reading comprehension. In a longitudinal study, they sampled a group of monolingual English children at Grade-3, and later at Grade-5 to test whether the multiplicative SVR model had predictive as well as concurrent validity. Decoding was measured by asking the children to read low-frequency phonetically regular monosyllable real words varying in length and orthographic complexity. Language comprehension and reading comprehension were measured. Two years later, reading comprehension was sourced from school records when the children reached Grade-5. Correlations revealed that decoding (r = .42) and language comprehension (r = .38) were strongly related to reading comprehension at Grade-3. Similar to Hoover and Gough (1990), the relationship between reading comprehension at Grade-5 and language comprehension increased (r = .46), however, contrary to results from Hoover and Gough (1990), the relationship between decoding and Grade-5 reading comprehension did not decrease, but actually increased (r = .62). The SVR model was tested using a regression model that included both the linear (additive) term and the product term. The analysis revealed that the additive model of decoding and language comprehension accounted for 43.9% of variance in Grade-3 reading comprehension, and the addition of the product model did not significantly account for any unique variance, contrary to the findings from Hoover and Gough (1990). Grade-3 decoding and language comprehension were then entered into a model to test whether these skills could predict Grade-5 reading comprehension. While the product term did significantly account for unique variance over the linear term, when entered in the reverse order the additive model accounted for more unique variance, over and above the product. Thus, Dryer and Katz (1992) concluded that the additive model of the SVR components had more predictive and concurrent validity than the product model.

Later, Chen and Vellutino (1997) sampled another monolingual population and found that the additive model of the SVR was superior to the product model at predicting reading comprehension. Chen and Vellutino analysed reading skills from children Grades-2 to 6 and used a hierarchical regression that included both the additive model and the product model, RC = D + LC + (D x LC). They found that the product term rarely explained further proportions of variance in reading comprehension after controlling for the additive term. Similarly, using structural equation modelling, Kershaw and Schatschneider (2012) demonstrated that both the additive model alone, and the combined model of the additive and product models had a good model fit to the data whereas the product model did not in three samples of students at Grade-3, 7 and 10. A chi-square test further indicated that the difference in model fit was statistically significant. These findings of an advantage of the additive or the combined model over the product model in explaining variance in reading comprehension have been further supported in several other studies (e.g., Connors; 2009, Savage, 2006; Savage & Wolforth, 2007; Dreyer & Katz, 1992; Neuhaus et al., 2006; Tiu, Thompson & Lewis, 2003). Similar to what was suggested by Connors (2009), Kershaw and Schatschneider (2012) also found that the additive model was a better fit for readers in Grade-3 and concluded that the product model may be most relevant in samples with the full range of skill (i.e., when some skill values are at zero or close to zero).

Some studies however have reported that neither model provides an advantage over the other in explaining the variance in reading comprehension. Georgiou, Das and Hayward (2009) found that the additive model and the product model of the SVR fitted the data equally well in a sample of 50 children in Grades-3 and 4. Savage and Wolforth (2007) later replicated Chen and Vellutino's (1997) study in a group of graduate and undergraduate university students with and without diagnosed reading disorders. Principal components analyses were used to combine several measures of decoding (speed and accuracy of word and nonword reading and spelling), language comprehension (close-type passage comprehension task), and reading comprehension (timed passage reading with comprehension questions) into latent variable measures. Vocabulary and Rapid Automatised Naming (RAN) skills were also measured. Using the same *additive plus product model,* RC = D + LC + (D x LC), again the authors found that the additive model explained around half the variance in reading comprehension in the sample, and that the product model did not explain any additional variance. When computed in reverse however, RC = (D x LC) + D + LC the additive model did not account for any unique variance either above or beyond the product model. The authors concluded that both models had similar predictive power in explaining the variance in reading comprehension. RAN was not found to be a good predictor of variance in reading comprehension and did not correlate with any of the measures of language comprehension or decoding. These results are also consistent with the view that RAN may not be a particularly strong correlate of word reading abilities (e.g. Savage, 2004; Vukovic & Siegel, 2006).

It is important to note that one limitation of this study is that the authors did not analyse typical readers and readers with a reading disorder separately. Again, it is possible that this range of skill in a sample of readers with and without reading disorders may have increased the strength of a product model, or it is equally possible that the predictive power of the multiplicative model was driven by one of the two groups. For the SVR to effectively be implemented into pedagogy, the SVR must be able to separately characterize readers with varying levels of skill. The current Chapter and subsequent Chapters in this thesis aim to test the SVR model separately in groups of varying reading skills to determine how the model might function in different samples of readers.

Taken together, these inconsistencies reported in the literature warrant further investigation of the SVR especially in different groups of readers (i.e., skilled readers, readers with impairments, or bilingual readers) to create an accurate profile of reading ability at any skill level. The current Chapter will examine the nature of the SVR in a sample of skilled adult readers of English, while subsequent Chapters will address other types of readers (i.e., bilingual readers and dyslexic readers).

It should be noted here that Gough and Tunmer (1986) suggest that the predictions of the SVR require a sample of participants whose reading skills are not so highly developed that their variability is restricted. However, since the SVR cannot always account for 100% variance in reading comprehension in developing readers, it is important to test the predictions of the SVR within a sample of skilled readers since Gough and Tunmer (1986) make predictions about instances when readers have perfect reading ability. Restricted variability may be sensitive to even the smallest differences. An evaluation of skilled readers can provide a picture of the ability of the SVR to account for variance in reading comprehension in highly developed readers, so results can be compared to less developed groups of readers (i.e., younger students and bilinguals). Further, dyslexia can often persist into adulthood, thus, if the SVR attempts to classify poor readers at any age, it should also classify skilled reading at any age. If the SVR cannot distinguish between skilled readers and poor adult readers, then a new theoretical framework may be needed to account for dyslexia in adult readers.

2.2.2.1 Proportion of Explained Variance in Reading Comprehension from The Simple View of Reading Model

Regardless of whether the best fitting model of the SVR is the product model or the additive model, there is also contention in the literature on how much variance in reading comprehension the two components (decoding and language comprehension) can explain. Further, it is unclear whether additional abilities that are not encompassed by the decoding and language comprehension components, might explain additional variance.

There is no consensus on how much variance in reading comprehension the SVR model can explain in a given sample. Although the SVR model claims the capacity to predict 100% of the variance in reading comprehension (Hoover & Gough, 1990), some studies that have tested the model have found that the SVR only accounts for less than half the variance in reading comprehension (e.g., 45%-47% Georgiou, Das & Hayward, 2009; 22%-23% Savage & Wolforth, 2007) while others have found the model to predict well over half of the variance in reading comprehension (e.g., 65%; Spear-Swerling, 2004; 79%-88%; Catts, Herrera, Nielsen & Bridges, 2015) for readers ranging from preliterate children (Chiu, 2018) to adults (Jackson, 2005; Savage & Wolforth, 2007). However, what appears to be consistent across the literature is that the two component skills (decoding and language comprehension) do not account for all the unique variance in reading comprehension.

These findings are particularly evident in studies that measure reading abilities across different ages. According to the SVR model, the proportions of variance accounted for by decoding and language comprehension would be different across skill levels, but together they should still account for all the variance in reading comprehension at all combinations of skill level. In practice however, this is not the case. For example, Tilstra et al. (2009)

sampled groups of students in Grades-4, 7 and 9 and found that the proportion of variance in reading comprehension that the SVR could account for may decrease with age. Specifically, their results revealed that the additive SVR model could account for 61% of the variance in reading comprehension for Grade-4 students, 48% for Grade-7 students, and 38% for Grade-9 students. The multiplicative model was not tested in this study.

A potential reason for this wide range of predicted values calculated from the SVR model, and some findings that decoding cannot account for unique variance in reading comprehension, may stem from the way the SVR component skills (decoding and language comprehension) are defined and measured. The decoding and linguistic comprehension components are, by design, broad terms to simplify the process of reading comprehension (Gough & Tunmer, 1986; Hoover & Gough, 1990). The SVR does not argue that reading only involves these two component skills, but rather that the variety of reading complexities and strategies can be categorized under one of these two components as subskills. For example, skills such as phonemic awareness and word/nonword reading abilities are considered subskills of the decoding component of the SVR, whereas skills such as, vocabulary knowledge, or grammatical awareness may contribute to the language comprehension component (see also Cain, Oakhill, & Bryant, 2004; Conners & Olson, 1990; de Jong & van der Leij, 2002; Juel, Griffin, & Gough, 1986; Neuhaus, Roldan, Boulware-Gooden, & Swank, 2006; Vellutino et al., 2007).

Studies have found support that there is a dissociation of the skills encompassed by each component category (decoding or language comprehension). For instance, Catts, Adlof, and Weismer (2006) measured a variety of reading abilities (i.e., word/nonword reading, vocabulary knowledge, discourse comprehension, grammatical understanding, phonological awareness and listening skills) at Grade-8, and retrospectively at Grades-2 and 4 in a sample of children identified at Grade-8 as either poor decoders or poor comprehenders. Results revealed that students with poor language comprehension skills also had the lowest overall composite scores from measures of language abilities including vocabulary, listening comprehension, discourse comprehension, and grammatical comprehension, but did not differ from typical readers on measures of phonological processing including a nonword repetition task and a phoneme deletion task. Poor decoders showed the opposite pattern, scoring well on tests of language comprehension, but poorly on measures of phonological processing. These patterns were also found to be stable across Grade levels. These results imply that there is a dissociation between subskills encompassed by either the decoding or language comprehension component skills. Oakhill, Cain, and Bryant (2003) found a similar dissociation between decoding and language comprehension skills longitudinally from children aged 7-8 and 8-9. Specifically, in their study, skills including text integration, metacognitive monitoring, and working memory were predictive of language comprehension skills, but not decoding ability, while a phoneme deletion task best accounted for variance in decoding ability. Since decoding and language comprehension are dissociated skill sets, they should then each account for unique variance in reading comprehension.

Recently, Hoover and Tunmer (2018) have noted that the original intent of the SVR model was to explain variance in reading comprehension at a broad level of analysis. However, this broad definition of decoding and language comprehension leaves room for various interpretations of such skills across studies. These interpretations also determine the way in which decoding and language comprehension are measured. Different language comprehension tasks may yield distinct contributions to reading comprehension across the literature. For example, Cutting and Scarborough (2006) created two language comprehension composite variables; (1) the lexical comprehension comprised of scores from two vocabulary tasks and a word meaning task and (2) a sentence processing score. Results revealed that the lexical composite variable consistently predicted higher proportions of variance in scores on several different reading comprehension tasks.

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The literature also reports substantial differences in the influence of decoding to reading comprehension with different measures of decoding. A recent meta-analysis of 110 studies by Garcia and Cain (2014) found that the correlation coefficients between decoding to reading comprehension ranged from .00 (Chen & Vellutino, 1997) to .96 (Katzir et al., 2006), though the corrected correlation average across studies was quite high (r = .74). Such a wide range may result from the type of tests used to measure decoding. For example, some studies that have used nonword/ pseudoword reading have found no contribution of decoding to reading comprehension (e.g., Bell & Perfetti, 1994; Jackson, 2005) while other studies using real word reading have found a unique contribution to reading comprehension (Berninger, Abbott, Vermeulen & Fulton, 2006; Nation & Snowling, 1997). Berninger et al. (2006) measured nonword and word reading in Grade-2 readers aged 7-8, at risk of a reading disability at two times; once in the Fall and once in the Spring. Reading comprehension was measured with four different tasks; sentence-level meaning judgment, a cloze task, a multiple-choice task, and an open-ended reading task. The tasks of real-word reading were consistently better predictors of each reading comprehension task than the nonword reading tasks. The authors did however find that the nonword decoding tasks predicted real word reading and concluded that though nonword reading may not be directly related to reading comprehension, it may be a skill that directly impacts real word reading which in turn impacts reading comprehension. Nation and Snowling's (1997) sample of 10-year-old readers showed similar patterns where word reading was more highly correlated with two measures of reading comprehension than nonword reading.

Tunmer and Greany (2010) acknowledged concerns that some researchers expressed about how decoding should be measured in the SVR (e.g., Braze, Tabor, Shankweiler, & Mencl, 2007). They suggest that decoding is a developmentally constrained skill and that for younger readers, a task that measures nonword reading may best reflect decoding skill for early-stage readers. As readers gain skill, context free word identification is recommended as the measure of decoding to assess the development of word-specific orthographic knowledge as well as letter-sound knowledge. For this reason, the current experiment assessed decoding in adult readers by using a context free word identification measure.

Similarly, the contribution of both decoding and language comprehension skills to reading comprehension may depend on the measure of reading comprehension used. Revisiting the previous examples, in Berninger's et al. (2006) sample real word decoding best predicted variance in the cloze reading task (72%) followed by the open ended question task (62%), the multiple choice task (28%) and the meaning judgement task (10%) in the Fall, and the same pattern was observed in the Spring with the cloze reading task (63%) followed by the open ended question task (59%), the multiple choice task (25%) and the meaning judgement task (10%). Similarly, in Nation and Snowling's (1997) sample real word decoding predicted 79% variance in a cloze reading task versus 53% for the question-and answer task. Similar results have been reported in other samples as well with decoding accounting for more variance in a cloze task than any other reading task (e.g., Spear-Swerling, 2004; Francis et al., 2005). For these reasons, the current experiment also used a cloze task to assess reading comprehension skill in adult readers.

2.2.2.2 The Role of Vocabulary as an Additional Predictor of Reading Comprehension

Although the SVR claims to account for all variance in reading comprehension, some researchers have suggested that some reading abilities such as attentional control (Connors, 2009), letter naming speed (Joshi & Aaron, 2000), or reading speed (Cutting & Scarborough, 2006) could explain additional proportions of variance in reading comprehension (Binder et al., 2017; Braze et al.l, 2007; Vellutino et al., 2007; Ouellette & Beers 2010; Tunmer & Chapman, 2012). Among these, oral vocabulary, or vocabulary knowledge, is an especially common variable that has predicted unique variance in reading comprehension above and beyond decoding and language comprehension. This may be a finding in some experiments but not in others, because researchers frequently use measures of vocabulary knowledge as a measure of the language comprehension component in the SVR (e.g., Catts, Herrera, Nielsen & Bridges, 2015; Cutting & Scarborough, 2006; Catts, Adlof, and Weismer, 2006).

When language comprehension is measured in with different metrics however, vocabulary knowledge often predicts additional variance. For instance, Tunmer and Chapman (2012) included vocabulary knowledge in a hierarchical regression with language comprehension and decoding and found that vocabulary knowledge made a significant contribution to the proportion of variance in reading comprehension explained beyond that made by decoding and language comprehension. Using structural equation modelling, the authors reasoned that this effect of vocabulary knowledge occurs because vocabulary knowledge contributed directly to the variance in decoding ability. Similarly, Kendeou et al. (2009) used a factor analysis to examine factors and their relative indicators of early reading skills in children aged 4 and 6. For both groups, two factors contributed to reading comprehension in their sample; decoding skills and language comprehension. Specifically, for children aged 4, the *Decoding Skills* factor consisted of phonological awareness, letter identification and vocabulary, while television comprehension (i.e., recall from watching a television show) and listening comprehension loaded onto the *Comprehension Skills* factor. Similar results were found for children aged 6, where the *Decoding Skill* factor consisted of phonological awareness, letter identification, word identification, and vocabulary while the factor *Comprehension Skills* comprised listening comprehension and television comprehension measures.

While it is outside of the scope of this thesis to compare every one of these types of decoding, language comprehension and reading comprehension measurements, it does recognise and address the importance of using tasks that are well supported in the literature to have internal reliability, and that have the capacity to measure the same skills across different groups (i.e., developing readings, skilled readers, and bilingual readers). Taken together, it would seem that using a real-word decoding task, a language comprehension task that involves listening, and does not directly measure vocabulary knowledge and a cloze activity reading task are the most reliable measures for decoding, language comprehension and reading comprehension respectively. For these reasons, subtests from the *Woodcock-Muñoz Language Survey III* (WMLS III; Woodcock, Alcarado, & Ruef, 2017) were used to measure participants' reading skills. The WMLS III is a norm-referenced, standardized test, versions of which have commonly been used in language studies to measure various reading skills (e.g., Barnes & Kim, 2016; Joshi, Tao, Aaron, & Quiroz, 2012; Nakamoto, Lindsey, & Manis, 2007). The WMLS III can be used to test individuals from age 2 through 90 and has been adapted to Spanish to test native Spanish speakers as well. Later, these skills will also be measured objectively using an eye-tracking paradigm.

The SVR has been widely supported across research studies investigating reading development and reading impairments in children (e.g., Hoover & Gough, 1990; Kendeou et al., 2009; Nation & Snowling, 1997; Oakhill, Cain & Bryant, 2003) however, very few studies have considered the model in adult readers, especially adult skilled readers (though see Jackson, 2005; Barnes & Kim, 2016; Barnes, Kim, Tighe & Vorstius, 2017; Savage & Wolforth, 2007). The well supported finding of a developmental shift in the influence of decoding and language comprehension skills would suggest that the SVR model would yield distinct results for skilled readers vs developing readers. Thus, this understudied group should be considered to extend support and validity for the SVR model.

2.2.3 Experiment 1: The Simple View of Reading in an Inconsistent Orthography

The goal of the current experiment was to consider the reading components described in the predictions of the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990) and to determine the extent to which decoding, and language comprehension abilities drive the strategies involved in skilled reading in an inconsistent orthography. Though previous experiments have tested the SVR model on skilled adult readers (e.g., Jackson, 2005; Savage &

Wolforth, 2007), there is no consensus as to how much variance this model can account for in skilled readers.

In addition, for the purpose of this thesis work, these skills also need to be tested in the current sample to later compare them with eye movements in *Experiment 2*, and with skills observed by dyslexic readers and Spanish-English bilinguals in subsequent Chapters. A model such as the SVR has both educational and diagnostic implications. Due to its supported effectiveness, the SVR has been used to implement literacy instruction and to provide interventions to students struggling with reading difficulties in classrooms. The Rose Report (2009) has adapted the use of the SVR in classrooms as a framework to develop curriculum in primary schools in the U.K. (Rose, 2009; DfES, 2006).

For these reasons, in *Experiment 1* reading abilities were measured in a sample of adult native English monolingual readers without reading impairments. The measures included the language components such as decoding, language comprehension and reading comprehension from the SVR (Gough & Tunmer, 1986), as well as vocabulary knowledge (from Turner & Chapman, 2012). The addition of a third variable as a factor predicting reading comprehension could also help shed light on the proportion of shared variance between language comprehension and decoding.

Hoover and Gough (1990) suggested that decoding ability for skilled readers is best measured from word identification tasks rather than nonword reading tasks. Accordingly, the present experiment will use a word identification task to measure decoding. Hoover and Gough (1990) also suggested language comprehension measures should encompass listening skills, vocabulary knowledge, and semantic integration. The current experiment will use a subtest from the Woodcock-Munoz Language Survey III (Woodcock, Alcarado, & Ruef, 2017) to measure each of these abilities (i.e., language comprehension, decoding skills, reading comprehension and vocabulary knowledge).

2.2.3.1 Hypotheses

The current experiment aimed to investigate the following hypotheses:

1. It was predicted that both decoding and language comprehension should be highly correlated with reading comprehension, but less correlated with one another as the SVR states that these components are independent from each other. It was also predicted that each variable should be able to account for some of the variance in reading comprehension on their own, but that their combination should account for greater variance. Given that research has observed that decoding is of a greater influence for non-skilled readers and that language comprehension becomes a greater influence as readers gain skill (Caravolas et al., 2019; Barnes & Kim, 2016; Goswami, 2002; Gough & Tunmer, 1986), it was also expected that the language comprehension scores should be better than decoding scores at predicting reading comprehension scores.

2. According to the SVR formula, the multiplicative interaction of decoding (D) x language comprehension (LC), would be a better predictor of reading comprehension than the linear combination of the two (RC = D + LC). However, recent studies with adult readers have found evidence that both an additive and multiplicative model have equal predictive power (e.g., Savage & Wolforth, 2007). Thus, it was expected that both the additive model and the multiplicative model would be adequate in accounting for variance in reading comprehension in a sample of skilled adult readers.

3. A final goal of this experiment was to explore whether vocabulary knowledge could predict reading comprehension above and beyond the SVR components in our sample. Vocabulary knowledge have been influential additions to the SVR model in previous research (Binder et al., 2017; Braze Tabor, Shankweiler & Mencl, 2007; Vellutino et al., 2007; Ouellette & Beers 2010; Tunmer & Chapman, 2012). Thus, it

was expected that vocabulary knowledge would explain additional variance above and beyond decoding and language comprehension for the current sample.

2.2.4 Methods

2.2.4.1 Ethics Statement

Both *Experiment 1 and 2* were approved by the Institutional Ethical Review Board, Brunel University London, Department of Psychology, United Kingdom (number IP -IRB/11942-LR-Aug/2018- 13812-2) (see Appendix 1). Written informed consent was obtained from each participant (see Appendix 2b), after participants read an information sheet (see Appendix 2a) about the purpose of the experiment and their right as participants to withdraw at any point in time without giving a reason.

2.2.4.2 Participants

The sample consisted of 52 English monolingual readers aged 18-30 (46 females M_{age} = 20.04, SD = 4.53), who were recruited from Brunel University London's research pool and participated for course credit. All participants had normal or corrected-to-normal vision and were monolingual English speakers.

2.2.4.3 Measures and Materials

Subtests from the *Woodcock-Muñoz Language Survey III* (WMLS III; Woodcock, Alcarado, & Ruef, 2017) were used to assess participants' language skills, which are vocabulary knowledge – Picture Vocabulary, decoding skills – Letter-Word Identification, language comprehension – Verbal Analogies and reading comprehension – Passage Comprehension. The WMLS III is a norm-referenced, standardized test, versions of which have commonly been used in language studies to measure various reading skills (e.g., Barnes & Kim, 2016; Joshi, Tao, Aaron, & Quiroz, 2012; Nakamoto, Lindsey, & Manis, 2007). The WMLS III can be used to test individuals from age 2 through 90.

Vocabulary Knowledge

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The WMLS III Picture Vocabulary subtest, henceforth referred to as *vocabulary knowledge*, was used as a measure of English vocabulary knowledge (Woodcock, Alcarado, & Ruef, 2017). In this subtest, participants were shown a series of pictures of objects (e.g., a tricycle) and asked to provide the names of the objects that they see. There were 56 items in total in this subtest and participants were scored based on the number of correct responses. This subtest has a reported median internal consistency reliability coefficient of .86.

Decoding Skills

The WMLS III Letter-Word identification subtest, henceforth referred to as *decoding*, was administered as the measure of English decoding ability (Woodcock, Alcarado, & Ruef, 2017). In this subtest, participants were asked to read a series of increasingly difficult and less-frequent polysyllabic words (e.g., chorused; gouache). There were a total of 76 items in this subtest and participants were scored based on the number of correct responses. This subtest has a reported median internal consistency reliability coefficient of .91.

Language Comprehension

The WMLS III Verbal analogies subtest, henceforth referred to as *language comprehension*, was administered to measure language comprehension in English (Woodcock, Alcarado, & Ruef, 2017). In this subtest, the experimenter read the beginning of an analogy and the participant was asked to complete it orally. For example, the experimenter would read "Mother is to Father, as Sister is to _____" and the participant should answer with "Brother". This subtest requires listening, reasoning and vocabulary skills to complete each item. There were a total of 39 items in this subtest and participants were scored based on the number of correct responses. This subtest has a reported median internal consistency reliability coefficient of .89

Reading Comprehension

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The WMLS III Passage Comprehension subtest, henceforth referred to as *reading comprehension*, was administered as a measure of English reading comprehension, (Woodcock, Alcarado, & Ruef, 2017). In this subtest, participants were presented with a cloze activity where they were asked to silently read a series of passages and supply the missing word for each passage. There were 53 items in total in this subtest and participants were scored based on the number of correct responses. This subtest has a reported median internal consistency reliability coefficient of .90. Item number 42 (see Appendix 4) in the English version of this task was removed from analysis because the answer was an American term that is very rare in British English leaving a total of 52 items.

2.2.4.4 Procedure

The experiment lasted approximately twenty minutes and was completed in a laboratory at Brunel University London's campus. Upon entering the lab, participants were asked to read a participant information sheet (see Appendix 2a) and complete a subsequent written consent form (see Appendix 2b) where participants were informed that they were able to withdraw from the experiment at any time without having to give reason. Participants also completed a demographics and language history questionnaire (see Appendix 3).

Administration of the WMLS III followed the standard procedure as outlined in the testing manual. The experimenter began each subtest by reading the instructions and administering two practice items to ensure that the participant understood the directions. Testing then began with an age-appropriate item (since all participants were aged 18 or older and in university, they all began with the same item set). First, a base level was established, if one or more items of the first set of six were incorrect, testing continued with the previous set until all items in a set of six were correct. The item sets prior to the base level were counted as correct responses. Testing then continued with the subsequent sets until six items in a row were answered incorrectly, or when the last item was administered. The number of correct responses was recorded and used for analysis.

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After participants finished testing, they were given the participant information sheet to provide them with contract details should there be any further questions or problems.

2.2.5 Results

2.2.5.1 Descriptive Statistics for Monolingual English Readers without Dyslexia

Number of correct responses were recorded for each participant on each of the WMLS III subtests (Woodcock, Alcarado, & Ruef, 2017). Means raw scores and standard deviations for each reading ability measure are tabulated in Table 1.

Table 1. Descriptive Statistics for Reading Ability Scores for Native English Readers

Subtests	*N* Total Items	Range	Mean	SD
Language Comprehension	39	18 - 37	28.87	3.59
Vocabulary Knowledge	56	36 - 56	42.10	3.40
Decoding Skills	76	65 - 76	70.19	2.93
Reading Comprehension	52	35 - 51	43.63	3.39

2.2.5.2 Correlation Analysis Monolingual English Readers without Dyslexia

The scores from the WMLS III (Woodcock, Alcarado, & Ruef, 2017) were correlated with each other with Bonferroni corrected alphas of .013. As shown in Table 2, there was a significant positive correlation between language comprehension scores and vocabulary knowledge scores, $r(52) = .64$, $p < .001$, decoding scores $r(52) = .45$, $p < .001$, and reading comprehension scores $r(52) = .64$, $p < .001$. There was also a significant positive correlation between vocabulary knowledge scores and decoding scores $r(52) = .49$, $p < .001$, and reading comprehension scores $r(52) = .64$, $p < .001$. Finally, there was a significant positive correlation between decoding scores and reading comprehension scores *r*(52) = .47, $p <$ .001.

Table 2.Correlations of Language Abilities for Monolingual English Readers without Dyslexia

	Language Comprehension	Vocabulary Knowledge	Decoding
Language Comprehension			
Vocabulary Knowledge	.58***		
Decoding	.45***	.48***	
Reading Comprehension	.64***	.69***	.47***

Note: correlation is significant at the $p > .001$***

These correlations will be explored as regressions in the following sections especially with reference to the SVR (Gough & Tunmer, 1986). Since these measures were highly correlated with one another (see Table 2), we also tested for multicollinearity using the variance inflation factor (VIF). A high degree of multicollinearity poses a problem to the regression because it increases the variance of the regression coefficients, making them unstable. A VIF over 5 indicates high correlation and is generally suggested as a cut-off point (e.g., Simon, 2009). All variables had VIFs < 5, indicating that collinearity was not a problem.

2.2.5.3 Regression Analysis for Monolingual English Readers without Dyslexia

Simple linear regressions were calculated to see which of the component skills, i.e., decoding skills or language comprehension skills predicted reading comprehension separately. As shown in Figure 4, it was found that D (decoding) significantly predicted RC (reading comprehension) $t(52) = 3.71$, $p < .01$, $R^2 = 0.21$. The model accounted for 21% of the variance in reading comprehension and predicted that reading comprehension scores would increase by 0.54 points for each additional decoding score point.

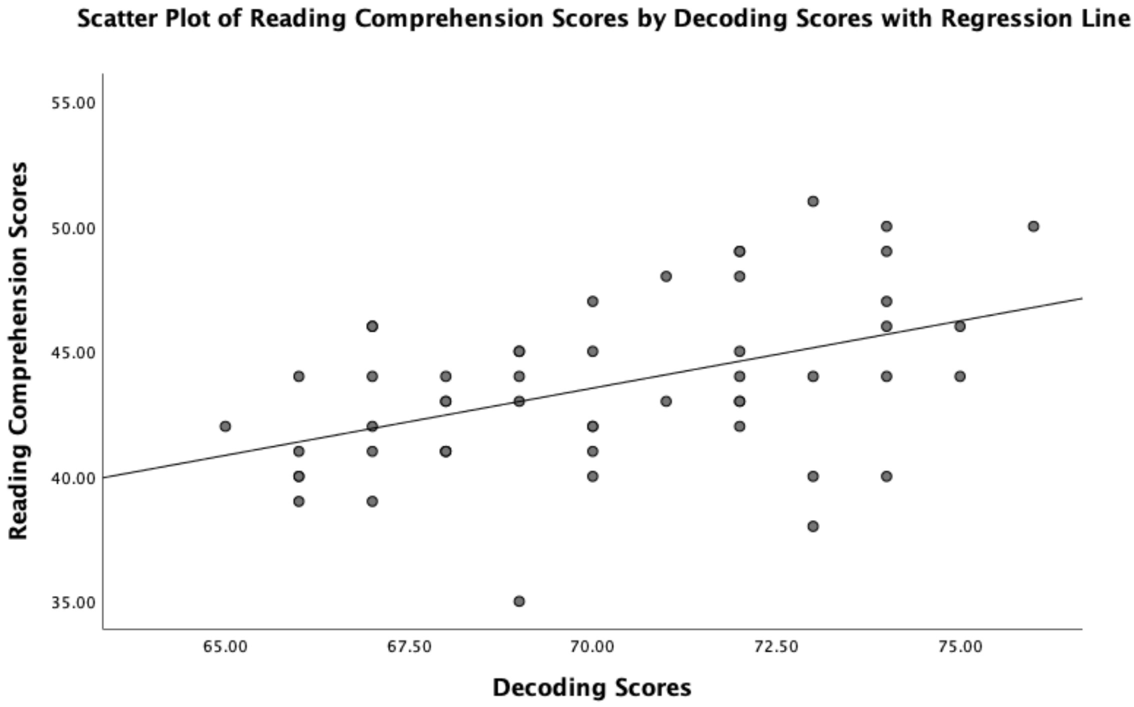

Figure 4. Correlation between Decoding Scores and Reading Comprehension Scores for Monolingual English Readers without Dyslexia

As shown in Figure 5, language comprehension was also a significant predictor of reading comprehension for English $t(52) = 5.96$, $p < .001$, $R^2 = 0.41$. The model accounted for 41% of the variance in reading comprehension and predicted that reading comprehension scores would increase by 0.61 points for each additional analogy point score.

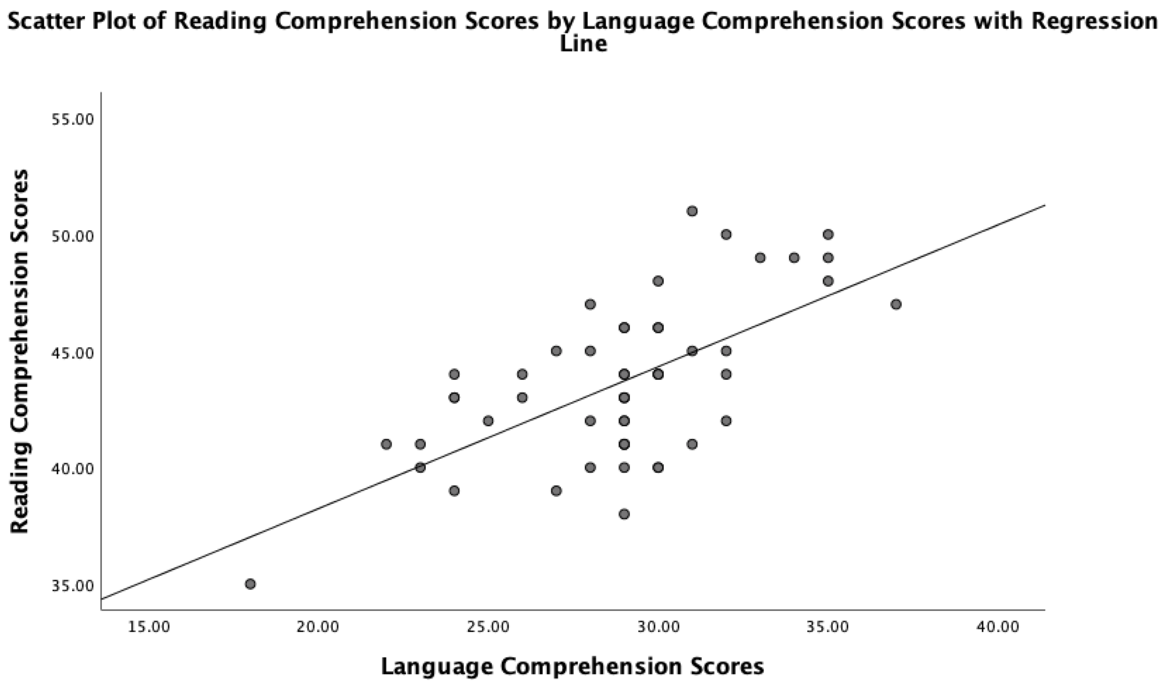

Figure 5. Correlation between Language Comprehension Scores and Reading Comprehension Scores for Monolingual English Readers without Dyslexia

Next, the pattern of correlations among each reading ability (decoding and language comprehension) was examined using hierarchical regressions to predict reading comprehension.

A hierarchical regression examined whether language comprehension and decoding predicted reading comprehension better than decoding alone (Table 3). Overall, Model 1 was significant $F(1,51) = 12.54$, $p < .001$,$R^2 = 0.20$, such that decoding explained 20% of the variation in reading comprehension. Adding language comprehension to the model did produce a significant improvement on Model 1, $\Delta F(1,49) = 21.34$, $p < .001$, such that overall Model 2 was significant $F(2,51) = 19.54$, $p = .001$, $R^2 = 0.45$, and now explained 45% of the variation in reading comprehension ($\Delta R^2 = 24.5\%$). As shown in Table 3, language comprehension ($\beta = .55$) emerged as a stronger predictor of reading comprehension than decoding ($\beta = .22$), which was not a significant predictor in this model ($p = .184$).

Table 3 Beta Weights in Hierarchical Regression Model Predicting Reading Comprehension with the SVR Component Skills for Monolingual English Readers without Dyslexia

		B (SE)	**β**	***t***	***p***
Model 1	Constant	6.70 (10.42)			
	Decoding	.53 (.15)	.45	3.54	.001
Model 2*	Constant	9.95 (8.79)			
	Decoding	.26 (.14)	.22	1.88	.066
	Language Comprehension	.54 (.12)	.55	4.62	.000

* indicates a significant model improvement

2.2.5.4 Simple View of Reading for Monolingual English Readers without Dyslexia

The SVR formula (Gough & Tunmer, 1986) was then tested on these data. The SVR postulates that the multiplicative combination of decoding and language comprehension (RC = D x LC) will be a better predictor of reading comprehension than the linear combination of decoding and language comprehension (RC = D + LC).

First, a new variable was computed by multiplying the decoding and language comprehension variables. Then, reading comprehension was regressed on the resulting multiplied variable to test the Decoding x Language Comprehension product model as a predictor of reading comprehension. As shown in Figure 6, the regression revealed that the product model significantly explained 43% of variance in reading comprehension for English readers $t(52) = 6.12$, $p < .001$, $R^2 = 0.43$.

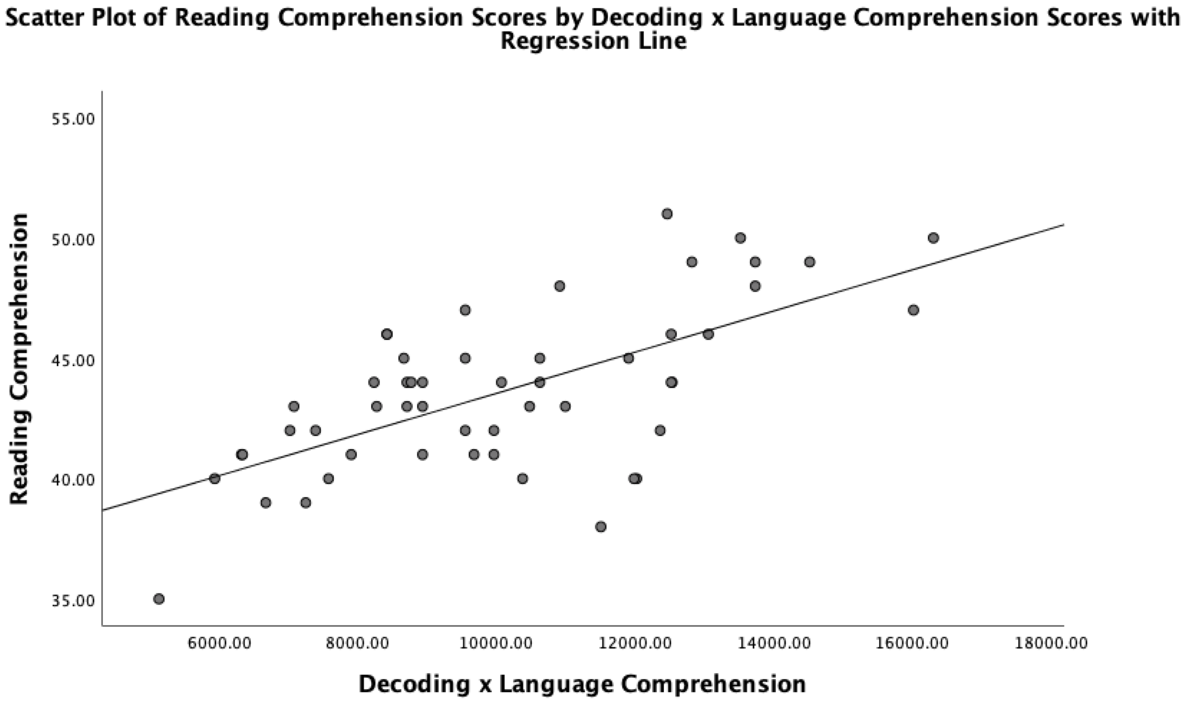

Figure 6. Correlation between the Product of Decoding and Language Comprehension Scores and Reading Comprehension Scores for Monolingual English Readers without Dyslexia

Next, multiple regressions examined whether the product model (RC = D x LC) would predict unique variance over the additive model (RC = D + LC) of the SVR (Gough & Tunmer, 1986) and are demonstrated in Table 4. Decoding and language comprehension were entered singly in the first two steps of regressions as an additive mode with reading comprehension as the outcome variable. The additive model was significant $F(2,51) = 20.35$, $p < .001, R^2 = .45$, such that this model explained 45% of the variation in reading comprehension. The addition of the product term as a third step in the regression model yielded an overall significant model, $F(2,51) = 13.59$, $p < .001, R^2 = .46$, and accounted for an additional 0.6% of variance, however this increase was not significant ($p = .475$).

When the same procedure was done in reverse, the product model alone was significant $F(2,51) = 37.48$, $p < .001, R^2 = .43$, and the addition of the decoding and language comprehension in the next steps accounted for a non-significant ($p = .264$) additional 3.1% of the variance in reading comprehension.

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Table 4. Beta Weights in Multiple Regression Model Predicting Reading Comprehension Decoding and Language Comprehension for Monolingual English Readers without Dyslexia

		B (SE)	**β**	***t***	***p***
Model 1	Constant	10.93 (8.65)			
	Decoding	.26 (.14)	.22	1.88	.066
	Language Comprehension	.54 (.12)	.55	4.62	.000
Model 2	Constant	62.47 (72.04)			
	Decoding	-.44(.98)	-.38	-.45	.653
	Language Comprehension	-.05 (.79)	-.05	-.06	.954
	Product (D x LC)	.001 (.002)	1.02	.72	.475
Model 1	Constant	35.00 (1.45)			
	Product (D x LC)	.001 (.00)	.655	6.12	.000
Model 2	Constant	62.47 (72.04)			
	Product (D x LC)	.001 (.00)	1.02	.72	.475
	Decoding	-.44(.98)	-.38	-.45	.653
	Language Comprehension	-.05 (.79)	-.05	-.06	.954

* indicates a significant model improvement

2.2.5.5 Vocabulary Knowledge for Monolingual English Readers without Dyslexia

Vocabulary knowledge has been influential additions to the SVR model in previous research (Binder et al., 2017; Braze et al., 2007; Ouellette & Beers 2010; Tunmer & Chapman, 2012; Vellutino et al., 2007). Thus, vocabulary knowledge was added to the previous models to determine whether this skill could predict reading comprehension above and beyond the component skills in the SVR, i.e., decoding and language comprehension.

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First, a simple linear regression was calculated to see whether vocabulary knowledge predicted reading comprehension on its own. As shown in Figure 7, a simple linear regression revealed that vocabulary knowledge was a significant predictor of reading comprehension on its own $t(52) = 6.63$, $p < .001$, $R^2 = 0.47$. To be exact, the model accounted for 47% of the variance in reading comprehension.

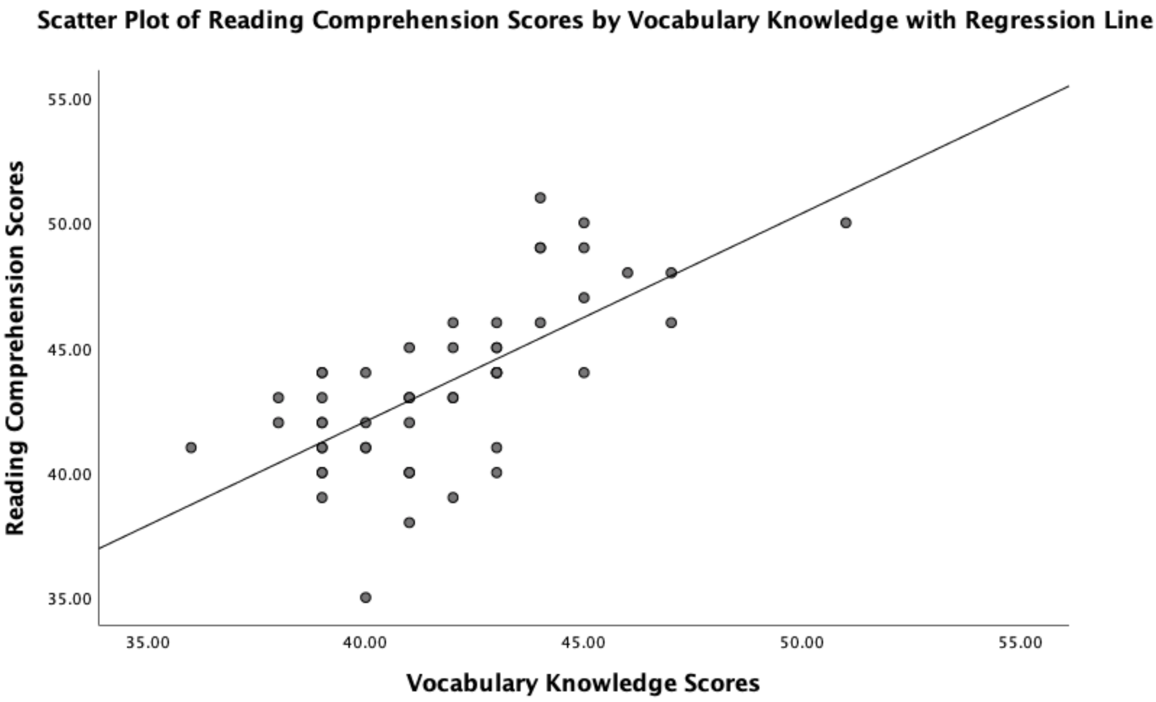

Figure 7. Correlation between Vocabulary Knowledge Scores and Reading Comprehension Scores for Monolingual English Readers without Dyslexia

Next, vocabulary knowledge was added to the previous hierarchical models which included decoding and language comprehension. Vocabulary knowledge was added as a third step was included to test whether this skill would predict reading comprehension scores above and beyond decoding and language comprehension scores (Table 5). Model 3 did significantly improve upon Model 2, $\Delta F(1,48) = 12.58$, $p < .001$, such that Model 3 was significant overall $F(3,51) = 20.37$, $p < .001$, $R^2 = 0.57$, and explained 57% of the variance in reading comprehension ($\Delta R^2 = 12\%$). As shown in Table 5, vocabulary ($\beta = .44$) emerged as the strongest predictor of reading comprehension, followed by language comprehension (β = .34), and decoding (β = .10), which was not a significant predictor in this model, (*p* = .262).

Table 5. Beta Weights in Hierarchical Regression Model Predicting Reading Comprehension with Three Reading Abilities for Monolingual English Readers without Dyslexia

		B (SE)	**β**	***t***	***p***
Model 1	Constant	6.70 (10.42)			
	Decoding	.53 (.15)	.45	3.54	.001
Model 2	Constant	9.95 (8.79)			
	Decoding	.26 (.14)	.22	1.88	.066
	Language Comprehension	.54 (.12)	.55	4.62	.000
Model 3*	Constant	3.62 (8.09)			
	Decoding	.11 (.14)	.10	3.55	.393
	Language Comprehension	.34 (.12)	.34	2.81	.007
	Vocabulary Knowledge	.54 (.115)	.44	0.86	.001

* indicates a significant model improvement

These same steps were then conducted in reverse, and a hierarchical regression was performed examining whether vocabulary knowledge and language comprehension predicted reading comprehension better than vocabulary knowledge alone (Table 6).

In Model 1, the overall model was significant $F(1,51) = 43.97$, $p < .001$,$R^2 = 0.47$, such that vocabulary knowledge explained 47% of the variation in reading comprehension. Adding language comprehension to the model produced a significant improvement on Model 1, $\Delta F(1,49) = 9.28$, $p < .01$, such that overall Model 2 was significant $F(2,51) = 30.34$, $p < .001$, $R^2 = 0.55$, and now explained 55% of the variation in reading comprehension ($\Delta R^2 = 8.5\%$).

Reading Behaviour Between a Consistent and an Inconsistent Orthography

As shown in Table 6, vocabulary knowledge (β = .48) emerged as a stronger predictor of reading comprehension than language comprehension (β = .36).

Table 6. Beta Weights in Reverse Hierarchical Regression Model Predicting Reading Comprehension with Three Reading Abilities for Monolingual English Readers without Dyslexia

		B (SE)	**β**	***t***	***p***
Model 1	Constant	8.72 (5.27)			
	Vocabulary Knowledge	.83 (.13)	.69	6.63	.000
Model 2*	Constant	9.17 (4.87)			
	Language Comprehension	.36 (.11)	.36	3.04	.004
	Vocabulary Knowledge	.58 (.14)	.48	4.04	.000
Model 3	Constant	3.62 (8.09)			
	Language Comprehension	.34 (.12)	.34	2.81	.007
	Vocabulary Knowledge	.54 (.15)	.44	3.55	.001
	Decoding Scores	.112 (.13)	.10	.86	.393

* indicates a significant model improvement

Finally, the third step tested whether decoding scores would predict reading comprehension scores above and beyond language comprehension and vocabulary knowledge scores (Table 6). Model 3 did not significantly improve upon Model 2, ($\Delta F(1,48) = .74$, $p = .393$), however, as seen above, this model was significant overall $F(3,51) = 20.37$, $p < .001$, $R^2 = 0.57$, and explained 57% of the variance in reading comprehension ($\Delta R^2 = 0.7\%$).

2.2.6 Discussion Monolingual English Readers without Dyslexia

The aim of *Experiment 1* was to measure the extent to which the language components (decoding, language comprehension and reading comprehension) described in the SVR (SVR; Gough & Tunmer, 1986) may contribute to variance in reading comprehension in a sample of skilled readers of an inconsistent orthography. Specifically, the current experiment tested whether a multiplicative or an additive model of the SVR could better predict variance in reading comprehension. Of further interest, was the extent to which each of these individual reading abilities as well as vocabulary knowledge, contributed to reading comprehension on their own, and the extent of their relationship to one another. For this reason, four measures of reading skills; decoding, vocabulary knowledge, language comprehension and reading comprehension were examined in a sample of adult skilled readers of English, an inconsistent language.

As expected, decoding and language comprehension correlated more highly with reading comprehension than with each other, and language comprehension accounted for more variance in reading comprehension than did decoding, thus supporting the first two hypotheses. Results also revealed that the additive model explained more variance in reading comprehension (45%) for the current sample of adult skilled readers, but that neither model was a significant improvement over the other in a hierarchical regression, thus supporting Hypothesis-2 stating that both the additive model and the multiplicative model would be adequate in accounting for variance in reading comprehension in a sample of skilled adult readers. Finally, in support of Hypothesis-3 stating that vocabulary knowledge would explain additional variance above and beyond decoding and language comprehension for the current sample, the addition of vocabulary knowledge as a third variable significantly accounted for an additional 12% of variance in reading comprehension above and beyond decoding and language comprehension.

2.2.6.1 The Simple View of Reading Framework for Monolingual English Readers without Dyslexia

In the current sample of skilled adult readers, SVR variables strongly correlated with one another (see Table 2), but language comprehension and reading comprehension had the strongest correlations. Decoding skills also significantly correlated with each measure, however these relationships were not as strong as with language comprehension. As was predicted by Hypothesis-1, decoding and language comprehension were both more strongly correlated with reading comprehension than with each other. This makes sense given that the components are independent skills, but both necessary to contribute to reading comprehension, and accords with the predictions of the SVR (Tunmer & Gough, 1986).

Shared variance between decoding and language comprehension has been reported to increase with age and skill (Hoover & Tunmer, 1993; Keenan, Betjemann, & Olson, 2008). Connors (2009) points out that evidence has shown that decoding and language comprehension are not necessarily independent of one another and often found to be highly correlated (e.g., Conners & Olson, 1990; Keenan et al., 2006; Vellutino et al., 2007), though the SVR claims that they are independent skills. At first, shared variance between decoding and language comprehension seems to contradict the SVR model because the decoding and language comprehension components are generally considered to be largely independent skills. However, Tunmer and Hoover (1993) argued that this would make sense given that as readers acquire skill in reading increasingly difficult texts, which leads to more practice with each skill. As children learn to decode, they can begin to read more comprehensive texts, and as children begin to understand more comprehensive texts, decoding can in turn proceed to a higher capacity. A good example of this is learning about the spelling of tenses in English, when a word ends in an *e* (e.g., bore), the past tense will be pronounced differently to a word that ends in a consonant (e.g., assist). Discovering semantic properties of a word can lead to understanding the spelling and hence decoding of a word or a set of words.

The SVR also predicts that the predictive strength of the decoding component will decrease over the course of reading development while language comprehension will increase in predictive strength. In the current sample, the three measures of reading ability (decoding, vocabulary knowledge and language comprehension) correlated strongly with reading comprehension but that the magnitude of the correlation coefficients were much larger for the skills involved in language comprehension (language comprehension and vocabulary knowledge) than for the decoding skills. These findings supported Hypothesis-2, which states language comprehension scores should be better than decoding scores at predicting reading comprehension scores and are also consistent with the SVR and research that shows that decoding is of greater influence for novice readers of an inconsistent language, but that as those skills improve, language comprehension skills gain influence (Caravolas et al., 2019; Barnes & Kim, 2016; Goswami, 2002; Gough, Hoover, & Peterson, 1996; Gough & Tunmer, 1986).

For example, Tunmer and Chapman (2012) found that decoding accounted for 77% of the variance in reading comprehension, but that language comprehension only accounted for 46% of the variance in reading comprehension in a sample of 7-year-old students. Studies with skilled adult readers on the other hand have found that only language comprehension made a significant independent contribution to variance in reading comprehension while decoding did not (MacArthur, Greenberg, Mellard & Sabatini, 2010). In the participants in the current sample of adult readers (M_{age} = 20.04), decoding only accounted for 21% of the variance in reading comprehension while language comprehension accounted for 42%. Decoding did not make a significant contribution to R^2 in any of the models that included other reading abilities. This pattern of change over reading development also makes sense within the framework of the ODH (Katz & Frost, 1992). The ODH holds that readers of an inconsistent language will be highly dependent on decoding skills in the early years of development, but less so as readers gain skill in decoding. Thus, these results are consistent with the ODH.

The additive model (RC = D + LC) of the SVR explained 45% of the variation in reading comprehension, while the multiplicative model (RC = D x LC) accounted for 43% of the variation in reading comprehension in this sample. However, hierarchical regressions revealed that both models were adequate in explaining the variance in reading comprehension and that addition of either the product or additive term over the other did not result in an increase in unique variance explained thus supporting Hypothesis-3. A key assumption of the SVR is that in a multiplicative mode (RC = D x LC), if either of these variables is null in a reader's ability, or 0 ability, then no matter how much skill they have with the other variable, they will not successfully comprehend. In other words, both decoding and language comprehension skills are necessary, but not solely sufficient conditions for the development of reading comprehension (Gough & Tunmer, 1986).

In their initial sample, Hoover and Gough (1990) found that the product term of the SVR predicted reading comprehension above and beyond that of the additive relationships with reading comprehension. However, the sample they used was that of bilingual Spanish-English children. Although the difference between 43% and 45% is only marginal, we failed to find the same effect in the current sample of skilled monolingual English readers suggesting perhaps that the interaction between these component skills may yield a distinct relationship to reading comprehension. Previous research on English monolingual children reports similar findings. Chen and Vellutino (1997) also found that the interaction (i.e., multiplicative) effect of decoding and language comprehension did not add unique variance to reading comprehension above and beyond that of the linear combination of two components individually. Another set of studies on English monolingual teenagers and adults with reading delays also observed that an additive model was a better predictor of reading comprehension (Savage, 2006; Savage & Wolforth, 2007). The results from the current sample and previous research on monolingual English speakers may suggest that the contribution of the components individually to reading comprehension may better characterize monolingual reading in an inconsistent orthography than the multiplicative relationship between the components. These findings may also imply that both decoding and languages comprehension skills may not be strictly necessary in an inconsistent language to have some level of skill in reading comprehension.

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However, as pointed out by Tunmer and Greany (2010), fitting the product model versus the additive model to explain variation in reading comprehension may depend on whether the tested sample represented a full range of scores in both decoding and language comprehension. Though the current sample did demonstrate a range of scores, perhaps it was not wide enough to properly test this contention. Further research is needed with wider ranges to address this question.

2.2.6.2 The Addition of Vocabulary Knowledge as a Third Predictor of Skilled Reading for Monolingual English Readers without Dyslexia

Recently, studies have shown that a third component, vocabulary knowledge, may be of extra importance to reading comprehension skills (Binder et al., 2017; Braze Tabor, Shankweiler & Mencl, 2007; Ouellette & Beers 2010; Share, 2004; Tunmer & Chapman, 2012). In the current sample, the strongest correlation between the SVR variables and vocabulary knowledge was between reading comprehension scores and vocabulary knowledge scores at (.70). Vocabulary knowledge has a higher correlation with reading comprehension than either decoding or language comprehension. MacArthur, Greenberg, Mellard and Sabatini (2010) found similar patterns of correlations in their study of college aged skilled English readers. Specifically, in their study, they found that vocabulary and language comprehension scores correlated more strongly with one another than with decoding and were more strongly correlated with reading comprehension than was decoding. Savage and Wolforth (2007) also reported a similar pattern of results in another sample of university students.

In the current sample, vocabulary knowledge also made a significant contribution to the variance in reading comprehension of 6.1% above and beyond that of decoding and language comprehension thus supporting Hypothesis-4. These findings do not support the SVR which holds that vocabulary should be encompassed by the language comprehension component. The measure of language comprehension used in the current experiment

(*Analogies*; WMLS III; Woodcock, Alcarado, & Ruef, 2017) indeed required a substantial vocabulary knowledge to listen and respond correctly to the items. Yet inclusion of a separate measure of vocabulary knowledge to the SVR model significantly improved its predictive capacity. These results may be interpreted within a more recent theoretical framework of a different reading model, Perfetti and Hart's (2002) Lexical Quality Hypothesis (LQH). This model posits that when there are threats to lexical quality (i.e., when the orthography is inconsistent), skilled reading is supported by the availability of high-quality lexical representations. In this model, lexical representations may include a rich knowledge base of orthographic, phonological, and semantic-syntactic information about words. In the current experiment, the inclusion of vocabulary knowledge as a predictive variable of reading comprehension gives a more comprehensive account of our sample's lexical representations above and beyond that of language comprehension, and thus these results make sense within the framework of the Lexical Quality Hypothesis.

2.2.6.3 Limitations and Further Research

The results from the current experiment are informative, yet still limited. In its capacity to predict reading comprehension, the SVR model in our sample failed to account for even half the variance in reading. The inclusion of a third variable, vocabulary knowledge, significantly contributed to reading comprehension once both decoding and language comprehension were controlled for, but still only explained 56.6% of variance in reading comprehension. While these findings fail to support the SVR model of reading comprehension, these findings may make sense in terms of the Lexical Quality Hypothesis (Perfetti & Hart, 2002), which states that skilled reading in the face of poor decoding signals (i.e., when the orthography is inconsistent) will be supported by the quality of lexical representations. In this case, reading comprehension for skilled readers may involve several more reading abilities that were not measured in the current experiment such as a more extensive measure of oral vocabulary, or knowledge of homophones (Perfetti & Hart, 2002). Kirby and Savage (2008) also argued that the SVR was not a comprehensive model able to account for all the complexities involved in reading. They argue instead that the decoding and language comprehension components of the SVR can be seen as an outline of the greater complexities involved in each component. Future research would benefit from including a larger selection of reading ability measures.

Tunmer and Chapman (2012) argued that the SVR was never intended to be a complete theory that encompassed all aspects of reading comprehension, and that both the decoding and language comprehension components can be further deconstructed and analysed. The two components of the SVR are strong in their capacity to predict reading comprehension when measured correctly, but the model does not account for all the variance involved in skilled monolingual English reading comprehension. Further research is needed to improve upon the components in this model or indeed add further components. Future research may benefit from measuring a larger battery of skills in samples with similar characteristics to elucidate some of the additional factors that may be contributing to variance in reading comprehension.

2.2.6.4 Conclusion

The current experiment used the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990) as a framework for characterizing the developed skills involved in skilled monolingual English reading. It was expected that language comprehension and decoding should correlate more highly with reading comprehension than with each other and that language comprehension should account for more variance than decoding in reading comprehension for the current sample of skilled adult readers of English. Results supported both assertions and demonstrated that the SVR accounted for close to half the variance in reading comprehension in the current sample. However, results revealed that both the product model (RC = D x LC) and the additive model (RC = D + LC) were adequate in accounting for variance in reading comprehension, which supported our predictions in Hypothesis-3, but challenges the assertions of the SVR model. Further, the inclusion of a vocabulary skill component significantly added to reading comprehension in that the model with vocabulary skill, decoding skill and language comprehension skill could account for over half of the variance in reading in this sample. This model leaves just under half of the variance in reading comprehension unaccounted for. Overall, the SVR model was only partially supported and further research is needed to explore other models such as the Lexical Quality Hypothesis (Perfetti & Hart, 2002), and additional factors that may contribute to the other half of the variance not accounted for by the SVR model.

2.3 Experiment 2: Eye Movement Patterns in an Inconsistent Orthography

The results of *Experiment 1* in the current Chapter demonstrated a predictive pattern of reading abilities to reading comprehension in a sample of monolingual English skilled readers. When considering reading strategies, and current models of reading comprehension such as the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990), it is also useful to incorporate objective measures. Examining eye movements may reveal a greater understanding of the cognitive processes of reading, and comparing such processes to offline measures of reading may further develop the complete picture of reading. Understanding the specific relationships between eye movement behaviour measured online and individual reading skills based on the components involved in the SVR model measured offline in skilled English monolingual readers, was the primary goal of this section.

2.3.1 An Overview of Eye-Tracking Research and the Eye-Mind Link

The study of eye movements in reading tasks began in the 17th century with early observations by Louis Émile Javal, a French ophthalmologist (Henderson, 2006). Subsequent research began investigating specific patterns of reading as early as the 1900s, where basic observations were made, such that the eyes move across a text interrupted by short pauses (e.g., see Huey, 1908). Rayner (1998) reviewed 20 years of eye movement research in what he argued to be the “third era of eye movement research” (p. 372) marked by extensive advancement in technology (see also Wade & Tatler, 2005 for a review). During this era, eye-tracking studies focused on investigating eye movement patterns during several different information processing tasks such as visual search (e.g., Engel, 1977; Findlay, 1997; Viviani & Swensson,1982) scene perception (e.g., Antes, 1974; Friedman,1979; Friedman& Liebelt,1981; Mackworth & Morandi, 1967) and reading (e.g., Carpenter & Just, 1983; Frazier & Rayner, 1982; Inhoff & Rayner, 1986; Just, Carpenter & Woolley, 1982, Rayner, 1977; Rayner, 1978b). These studies revealed some important basic properties of eye movements and established that there are different decision processes involved in programming where and when to move the eyes in different information processing tasks. For example, different information processing tasks yield different sequences of fixations and saccades. Table 7 provides an overview of the differences in fixation duration and saccade size during several different tasks (see Rayner, 1998).

Table 7. Approximate Mean Fixation Duration and Saccade Length in Reading, Visual Search, Scene Perception, Music Reading, and Typing (From Table. 1 in Rayner (1998))

Task	Mean Fixation Duration (ms)	Mean Saccade Size (degrees)
Silent Reading	225	2 (about 8 letters)
Oral Reading	275	1.5 (about 6 letters)
Visual Search	275	3
Scene Perception	330	4
Music Reading	375	1
Typing	400	1

The findings from this era of research established the Eye-Mind Link Hypothesis which posits that there is a relationship between eye movement patterns and cognitive processes such as attention or reading (Just & Carpenter, 1980; Rayner, 1998; Reichle, 2006). In a rigid interpretation of the theory, Just and Carpenter (1980) hypothesized that there is “no appreciable lag between what is fixated and what is processed” (p. 331). However, it is now understood that there are latencies between visual and cognitive processes, and research has demonstrated that our attention may often focus on something outside of our fixation (e.g., Anderson, Bothell & Douglass, 2004; Horowitz et al., 2007; Reichle & Reingold, 2013). This finding is demonstrated in cued tasks (e.g., Engbert & Kliegl, 2003; Posner, 1980), where participants are asked to fixate on a central fixation point while a cue is presented to indicate the likely location of a stimulus in the periphery. Participants are faster to respond to stimuli when the cue is valid (i.e., indicates the actual location of a stimulus) than when it is invalid or absent. This validity effect demonstrates that attention can be shifted covertly even when fixations do not change.

Because of its high temporal sensitivity, eye-tracking can provide a robust measure of moment-to-moment processes in cognitive activities such as reading. While the eye-mind link is not as rigid as initially proposed, it is generally true that eye movements do reflect cognitive processing of stimuli. The Eye-Mind Link Hypothesis still provides a rough guide to most eye-tracking research and current models of eye movement control such as the *E-Z Reader* model (Reichle, Pollatsek, Fisher, & Rayner, 1998; Reichle, Pollatsek, & Rayner, 2012) and the *SWIFT* model (Engbert, Nuthmann, Richter, & Kliegl, 2005). These models have been evaluated and compared extensively by Reichle, Rayner, and Pollatsek (2003; 2006) thus, only a brief description will be offered in the current Chapter. The *E-Z Reader* model is a computational model described as a “cognitive-control, serial-attention model” (Reichle, Pollatsek, & Rayner, 2006) and assumes that an early stage of lexical processing called the *familiarity check* controls the movement of the eyes through text during reading. In the E-Z *Reader* model, attention is assumed to be allocated serially to process just one word at a time. The signal that initiates the eye movement processes and the signal that causes attention to shift are separate such that the completion of the familiarity check on $word_n$ causes saccadic programming and thus shifts attention to $word_{n+1}$. In contrast, the *SWIFT* model assumes that attention is allocated to process several words concurrently, but with a similar cognitive signal that initiates lexical processing. It is generally concluded in these reviews that the E-Z Reader model best predicts a large proportion of the variance in eye movement measures based on variables such as frequency and length effects, whose effect on word recognition has been independently established. Thus, an analysis of eye-movements is generally considered a valid method in revealing processes involved in reading.

2.3.1.1 Eye Movement Characteristics in Reading for Skilled Monolingual English Readers

The basic characteristics of eye movements during reading are relatively well understood, especially for skilled adult readers of English. Specifically, early eye movement research in reading identified two main eye movements that guide a reader through a text; fixations and saccades (Huey, 1908; Rayner, 1998). Saccades are rapid eye movements that move across a text separated by fixations, or short pauses in scanning of the text. Readers make these eye movements to bring regions of text into the fovea (i.e., the region where visual acuity is highest) for processing. In his review of 20 years' worth of eye movement research, Rayner (1998) noted several characteristics of saccades and fixations during reading reported from eye-tracking studies. Recently, these characteristics have been further validated by several studies using a co-registration of eye movements and brain potentials paradigm (for a review, see Dengo & Liversedge, 2020). Some important characteristics of skilled reading in monolingual English readers will be discussed below.

Saccades

Saccades are rapid eye movements, with velocities as fast as 500° per second, that guide the reader to the necessary pieces of information to successfully comprehend a text.

Saccades generally last between 20ms-40ms, during which time, vision is suppressed (Matin, 1974). Saccades mainly move forward in a text (i.e., from left to right in English texts) and generally span between seven to nine letters for skilled readers (Rayner, 1998; Joseph, Liversedge, Blythe, White, & Rayner, 2009). This letter span has been found to be static even when viewing text from different distances and different angles (Morrison & Rayner, 1981; O'Regan, 1983). Saccades that move backward from right to left are called regressions and comprise about 10%-15% of all saccades for skilled readers (Starr & Rayner, 2001). Regressions occur when the reader requires further processing of texts that were previously unprocessed or not understood (Starr & Rayner, 2001). Regressive saccades have been observed to indicate the reader is experiencing difficulty processing text (Liversedge, Paterson, & Pickering, 1998; Rayner, 1998). It also appears that skilled readers are able to target their saccades to upcoming words with considerable accuracy to ensure the optimal landing position (i.e., the location of the resulting fixation) and can target regressions to resolve ambiguity (Rayner, 1998; Rayner, 2009).

Fixations

Fixations are pauses between two saccades, where the eyes are relatively motionless. Since vision is suppressed during saccades, all information is processed during fixations. On average, fixations last between 200-250ms, but can range from 100ms-500ms for skilled readers of English (see Rayner, 1998 for a review). Fixations are more frequently observed in words with three or more letters and often land at the beginning or middle of a word depending on word length. While readers fixate on approximately 70% of words in a text, around 30% of words are not fixated on. This phenomenon is referred to as *skipping* and is best predicted by length and frequency of words (Rayner, Slattery, Drieghe, & Liversedge, 2011). For example, content words are fixated about 85% of the time, whereas function words (i.e., *the, are, is, at,*) are fixated only about 35% of the time because they are much more frequent (Blanchard, Pollatsek, & Rayner, 1989; Carpenter & Just, 1983; Rayner &

Duffy, 1988). Additionally, as word length increases, the probability that a word will be fixated also increases. Words with only 2-3 letters are fixated much less often than longer words, and words with 8 or more letters are almost always fixated (Blanchard, Pollatsek & Rayner, 1989; Rayner & McConkie, 1976).

Importantly, it appears that words that are skipped are still processed (Drieghe, Rayner & Pollatsek 2005; Gordon, Plummer & Choi, 2013; Rayner, 1998) Fisher and Shebliske (1985) asked two groups of students to read sentences while their eye movements were being monitored. The first group read sentences as normal, while the researchers kept track of the words that were skipped. The second group then read the same sentences, but with the skipped words removed. Compared to the first group, the second group had slower reading time and longer fixations indicating that they had a more difficult time understanding the text when the word was missing than the readers who had access to the same word but did not fixate on it.

It is now well supported in the literature that such results occur because fixations enable both foveal and parafoveal processing (for a review see Schotter, Angele, & Rayner, 2012). The fovea region corresponds to the central 2° of the visual field, while the parafoveal region can range up to 5° of visual angle from fixation (Rayner, 1998, 2009). It has been well established that readers can pre-process information in the parafovea region to aid in processing of information in the fovea. Referred to as a preview benefit, this phenomenon has been well demonstrated in the boundary paradigm (Rayner, 1975), where an invisible boundary is just to the left of a target word and before the reader's eyes cross the boundary, a preview word is in the place of the target. The preview is typically different from the target word (e.g., a random string of letters or an orthographically similar nonword). Once the eyes cross the boundary, the preview word is instantly replaced with the target word during a saccade when vision is suppressed such that participants are typically not aware of the change (see also Rayner, 2009). This type of paradigm has demonstrated that participants spend less time fixating on the target if the preview word is either the same as the target or orthographically or phonologically similar versus a random letter string or an unrelated word. These findings indicate that the preview word is processed, and indicate that phonological and orthographic information can be integrated across saccades (for a review, see Rayner, 2009).

These results are consistent with eye movement studies investigating the size of the perceptual span in readers (e.g., Häikiö, Bertram, Hyönä, & Niemi, 2009; Rayner, 1986; Rayner, Slattery, & Bélanger, 2010). The *moving window technique* developed by McConkie and Rayner (1975) has been a useful paradigm used to demonstrate the visual span (foveal and parafoveal) during a fixation. In this paradigm, eye movements are measured while a participant views a text through a "window" that can be manipulated in size and location around a reader's fixation point to show more or less text. The participant can therefore only fixate on the text within the "window". For example, in a one-word sized window condition, a single word is presented normally while letters in surrounding text are converted to Xs. When the size and location of the window is manipulated, researchers are able to draw conclusions based on how information is extracted for each window size and location. The findings from these experiments have revealed that the region from which a participant can extract information is limited, and, in English, is asymmetric to the right of the fixation. In other words, for readers of English, the span extends from the beginning of the currently fixated word but no more than 3-4 letters to the left of fixation (McConkie & Rayner,1976a; Rayner & Pollatsek, 1987) to about 14-15 letter spaces to the right of fixation (Blanchard, Pollatsek & Rayner, 1989; McConkie & Rayner, 1975; Underwood & McConkie, 1985). If the window size is restricted to be any smaller than that, reading speed is slowed, the average length of a forward saccade decreases, the number of regressive saccades increases, and the average duration of a fixation increases (Blanchard, Pollatsek & Rayner, 1989).

While fixations and saccades are informative measures of reading and word-recognition processes, researchers often use a wider range of measures which can reflect both temporal (when to move the eyes) and spatial (where to move the eyes) information. These measures may also reflect distinct stages of the word-recognition or reading process. Such eye movement measures and the advantage of using them in eye-tracking paradigms will be discussed below.

2.3.1.2 Measuring Eye Movement Patterns During Reading

It is common in eye-tracking research to use a wide variety of eye tracking measures related to fixations and saccades to understand reading strategies. As discussed above, typical eye-tracking measures often include both spatial measures (i.e., fixation and regression count, and saccade length) as well as temporal measures (i.e., fixation duration and total reading time) (e.g., Korneev, Matveevn, & Akhutina, 2020; Liversedge, Paterson, & Pickering, 1998; Rayner, Chace, Slattery & Ashby, 2006; Rayner, 1998; 2009). These eye movement measures are assessed at both the word-level and the sentence-level and provide a general idea about the efficiency with which a text was processed. However, several other measures have been introduced that may distinguish between early and late processes of reading. These eye movements allow for investigation of both early and late effects of the experimental manipulation. Four common eye movement measures which reflect these processes include (i) first fixation duration, (ii) gaze duration, (iii) go-past time (also called regression path duration), and (iv) total reading time (e.g., see Inhoff, 1984; Morris, 1994; Rayner, 1998). Definitions for these eye movement measures can be found in Table 8.

Table 8. Early and Late Eye Movement Definitions.

Stage	Eye Movement Measure	Definition
Early	First Fixation Duration	The length of time the reader spends initially fixating on a word or region on the reader’s first pass through the sentence

	Gaze Duration	Gaze duration is the sum of all fixation durations (including first fixation duration) in a region or word during a first-pass reading, before the eyes fixate on a region that is either before or after the current one
Late	Go-past Time	Go-past time is the sum of all fixations before the eyes make a progressive movement to the right of a given word. This measure includes regressive fixations to previous regions
	Total Reading time	The sums all fixations made within a target area of text, including fixations made when re-reading

Research has found that these different eye movement measures may reflect distinct stages of comprehending a text (Kuperman & Van Dyke, 2011; Liversedge, Paterson, & Pickering, 1998; Rayner, Chace, Slattery & Ashby, 2006; Rayner, 1998; Rayner, 2009).

Early eye movement measures such as first fixation duration and gaze duration are assumed to reflect initial lexical access and early integration of information. These eye movements may process phonological information. For example, Pagán, Blythe and Liversedge (2021) have reported that first fixation durations and gaze durations are sensitive to misspelled words for both children and adults. Interestingly, adults were found to be most sensitive to words that had misspellings at the beginning compared to the middle or the end of each word, while children were sensitive to misspelled words no matter where the misspelling occurred. These results may also suggest that the more skilled readers are able to process larger grains of information at a time (i.e., morphemes or whole words) instead of relying on letter-by-letter decoding as children may still need to do, thus supporting the Psycholinguistic Grain Size Hypothesis (Ziegler & Goswami, 2005).

Results from priming experiments paired with an eye-tracking paradigm have demonstrated that participants process a target preceded by a phonologically related prime embedded in a sentence faster than a target preceded by a control word (Rayner et al, 1998; 2003; Sparrow & Miellet, 2002; Slattery, Pollatsek & Rayner, 2006). This phonological processing has been observed during the first 50 to 100 ms of the initial fixation on a word or region during reading, thus supporting early activation of decoding processes in reading comprehension (Rayner et al, 1998; 2003; Slattery, Pollatsek & Rayner, 2006; Sparrow & Miellet, 2002).

In contrast, late measures such as go-past time and total reading time are assumed to reflect higher order processes such as semantic integration, revision, and ambiguity resolution (Liversedge, Paterson, & Pickering, 1998; Rayner, 1998; Rayner, 2009). For example, regressions and second-pass eye movement measures such as go-past times indicate a reanalysis of text that has already been fixated upon at least once. Thus, the occurrence of these eye movements indicate some difficulty with the text and reflect the cost (in time) of overcoming these difficulties (Clifton, Stuab & Rayner, 2007).

Research investigating these eye movement measures in tandem with reading skills that explain variance in reading comprehension (e.g., the SVR) will provide a more comprehensive inspection of the reading process. The current experiment will monitor these eye movement measures while participants are instructed to read sentences for meaning to investigate early and late reading processes involved in reading. These eye movements will subsequently be compared to individual differences in the reading skills indicated in the SVR (i.e., decoding and language comprehension) that were measured in the previous *Experiment 1* in the current Chapter.

Although eye movement control during reading has been well established at a global level, there is also substantial variability in the eye movement ranges discussed above across readers and different kinds of texts. This has recently been a point of particular interest in eye movement studies on reading. Some factors that may influence variability in eye movement patterns relevant to this thesis will be discussed in the following section.

2.3.2 Factors that Influence Eye Movement Variability

Research investigating the relationship between eye movements and reading has found that there are two major factors that determine variation in eye movements; properties of words and texts being read and individual differences across readers.

2.3.2.1 Text-Level Influences

As previously discussed, a key finding is that eye movements reflect cognitive control and thus deciding where and when to move the eyes are influenced by factors that affect word identification. Clifton and Rayner (2007) review seven characteristics of texts that have been reported to affect eye movement measures: (1) word frequency, (2) word familiarity, (3) age-of-acquisition, (4) number of meanings, (5) morphology, (6) contextual constraint, and (7) plausibility. Although a thorough review of all of these characteristics is outside of the scope of this thesis, two characteristics that perhaps have the most robust effects on eye movement measures will be discussed; length effects, and frequency effects. These effects are also implicated in models of word reading such as the DRC (Coltheart et al.,, 2001) and the Triangle Model (Plaut, 1999; Plaut et al., 1996; Seidenberg & McClelland, 1989) discussed previously.

It is well documented that word length and word frequency influence the word recognition process. The general finding is that longer and less frequent words elicit slower response times during reading tasks than shorter and more frequent words (e.g., De Luca et al.,1999; Martens & de Jong, 2006; Weekes, 1997). Not surprisingly, length and frequency of words also appear to affect eye movements (for a review see Clifton, Staub, & Rayner, 2007). Similar to reaction times, words that are shorter in letter length, and words that appear more frequently in texts, are more likely to be skipped with fewer refixations, and receive fewer and shorter fixation durations, than longer or low-frequency words (Altarriba, Kroll, Sholl, & Rayner, 1996; Balota, Pollatsek, & Rayner, 1985; Brysbaert & Vitu, 1998; Drieghe, Desmet, & Brysbaert, 2007; Drieghe, et al., 2005; Jared, Levy & Rayner, 1999; Rayner & Duffy, 1986;

Rayner, 1979; Rayner & McConkie, 1976; Rayner et al., 2011; Vitu, O'Regan, Inhoff, & Topolski, 1995). Length and frequency effects have been reported in eye movements of both children (for reviews see Reichle et al., 2013; Blythe & Joseph, 2011) and adults (Just & Carpenter, 1980; Jared, Levy & Rayner, 1999; Rayner, 1998; 2009), with the typical finding that the effects are larger for children than they are for adults.

Effects of word length and frequency on eye movements during the word identification process can be conceptualised in terms of dual route models of visual word recognition (e.g., DRC, Coltheart et al., 2001), and some studies have also used this model to interpret length and frequency effects in eye movements (Blythe et al., 2011; Joseph, Nation, & Liversedge, 2013; Joseph et al., 2009; White & Liversedge, 2004). For example, Lowell and Morris (2014) observed that length effects were modulated by lexicality in eye movements. They tracked eye movements of readers of English while reading both long and short familiar words and novel words. Participants spent significantly more time re-fixating longer novel words compared to short novel words; however, there was no length effect (as revealed by eye movements) for familiar words. These results suggest that in inconsistent orthographies, such as English, more lexical knowledge can be applied to a word than a novel word which requires sub-lexical processing strategies (see Wood & Farrington-Flint, 2001 for nonword-reading by orthographic analogy).

Thus, similar conclusions can be drawn for eye movements as they have been for studies that report accuracy and reaction times. To review, the DRC hypothesizes that there are two competing procedures available to identify a given word, the sub-lexical procedure, and the lexical procedure. The slow sub-lexical route involves decoding grapheme-phoneme correspondences (GPC) while the fast lexical route identifies words through a direct connection between a written word form and its orthographic representation in the lexicon. Thus, word length effects on eye movements are presumed to indicate sub-lexical route procedure being used, where words are decoded letter by letter, in which case processing time increases with the number of letters to be processed. Larger length effects (i.e., the size of the difference between reading short words and long words) indicate a greater reliance on the lexical route.

As previously noted, an advantage of using an eye-tracking paradigm is the ability to parse the time-course of word identification by using both early and late-stage eye movement measures. For example, length and frequency effects that occur in early measures of reading, may reflect the processes that appear in the initial stages of reading (i.e., phonological access) whereas effects that appear at the late stage likely do not reflect these initial processes, but do reflect later processes of reading (i.e., conflict resolution and semantic integration). A few studies have directly examined the time-course of length and frequency effects as they occur in both early and late eye movement measures of reading. For example, Ashby, Rayner, and Clifton (2005) found that first fixation durations and gaze durations but not go-past times were sensitive to frequency effects in adult readers of English and that this effect was larger in average compared to skilled readers. From these findings, they concluded that it appears as though frequency effects are linked to early lexical processes that occur for initial word reading.

Hyona and Olsen (1995), and later Joseph and colleagues (2013) did not find length effects for first fixation durations, in typical readers, but they did find them in gaze durations and second pass reading times. Juhaz and Rayner (2003) used multiple regression techniques to investigate the influence of different factors on adult readers' first-fixation durations, single-fixation durations, gaze durations and total fixation duration during sentence reading. Frequency was found to predict each of the eye movement measures, but length effects were only found for gaze durations and total reading time. They concluded that the effect of word length on gaze duration and total reading time was likely due to the higher refixation probability associated with longer words (Rayner et al., 1996) as both measures include refixations either made during the first pass (gaze duration) or in the first and subsequent passes (total reading time).

Similarly, the time-course of length and frequency processes may also differ between adults and children (Blythe et al., 2011; Joseph, Nation, & Liversedge, 2013; Joseph et al., 2009). For example, Joseph et al. (2013) investigated frequency effects in the eye movements of adults compared to children (aged 8-9). Participants were asked to read sentences embedded with either high or low-frequency targets. No effect of frequency was found for first fixation durations for either the children or adults. Frequency effects were found for children, but not adults in gaze-durations. Finally, frequency effects were reported for both adults and children for total reading times, and this effect was larger for children such that both groups had slower total reading times for low compared to high-frequency words, however latencies between low and high-frequency words were longer for children. These results were interpreted to indicate that children showed frequency effects beginning in early stages of reading (i.e., gaze-durations) while adults only showed these effects in later measures of reading.

Taken together, it appears as though word length and word frequency are good predictors of eye movement measures, which in turn may reflect the use of lexical and sub-lexical reading strategies. In sum, word frequency appears to affect both early and late-stage eye movement measures of reading for English readers, while word length may only affect later eye movement measures. Thus, the time-course of length and frequency effects may indicate that frequency information may precede length information. These effects also seem to be larger for more experienced readers compared to less experienced readers. The next section will further discuss differences in eye movement measures as a function of skill level in various reading measures.

2.3.2.2 Individual Differences Influences

Eye movement patterns may also vary across readers as a function of different reading skills and much research has been devoted to this investigation (e.g., Ashby et al., 2005; 2012;

Barnes & Kim, 2016; Chace et al., 2005; Häikiö et al., 2009; Jared et al., 1999; Luke et al., 2015; Veldre & Andrews, 2014). On average, fewer, and shorter fixations paired with fewer and longer (amplitude) saccades indicate faster and more fluent processing strategies (Everatt & Underwood, 1994; Jared, Levy & Rayner, 1999; Rayner, 1998). This finding is especially evident between skilled and less-skilled readers. For instance, compared to children and dyslexic readers, skilled adult readers tend to make shorter fixations, longer (in distance) saccades and fewer regressions while reading, thus allowing them to process more information in a shorter time than less skilled readers (Blythe & Joseph, 2011; Everatt & Underwood, 1994; Rayner, 1978b; Underwood, Hubbard, & Wilkinson, 1990). Skilled adult readers also exhibit shorter gaze durations with fewer refixations compared to less skilled readers during normal text reading (Luke et al., 2015), implying that the skilled readers processed words faster and with less conflict-resolution than the less skilled reader.

Individual differences in word identification skills may account for more variance in eye movement patterns than word-level variables such as length and frequency. Kuperman and Van Dyke (2011) tested a sample of seventy adult readers on a battery of 18 different verbal and cognitive measures and measured their eye movements while they read sentences. Results demonstrated that rapid automatized letter naming (RAN) and word identification scores were the only variables that reliably predicted both early (i.e., first fixation position, first fixation duration, single fixation duration and gaze duration) and late-stage eye movements (i.e., go-past times, second pass reading times, and total reading times). Further, the effects of RAN and word identification scores on these eye movements were even greater in magnitude than length and frequency of words. On average, readers who had faster naming skills and better word identification skills had shorter durations for all these measures, and initial landing positions closer to the centre of words. Individual differences in RAN and word identification also modulated the influence of length and frequency effects on fixation times such that better word identification skills were associated with smaller gaze duration effects of word length.

The influence of individual differences on eye movements measures has also been investigated using reading comprehension tasks such as the Nelson-Denny test. For example, Ashby, Rayner, and Clifton (2005) categorized adult readers as skilled or average readers based on their scores from the Nelson-Denny reading test. Based on this distinction, skilled readers had shorter gaze durations, fewer regressions, and spent less time re-reading than average readers while reading target words that were predictable from sentences. A differential effect of word frequency and word predictability was found such that both groups read less frequent and low-predictability words slower, but latencies were longer for average readers. Thus, reading skill may interact with word predictability in the word recognition process. Similarly, Everatt and Underwood (1994) found that for a sample of college students a combination of participants' vocabulary scores, nonword lexical decision scores and gaze durations together could predict around half the variance in reading comprehension scores.

More recently, Eskenazi and Folk (2015) also found that university students categorized as having either high or low reading skill by the Nelson-Denny test showed differential effects of word-skipping when the foveal load was manipulated (i.e., the difficulty of the word prior to the target word) and when word length varied (three vs five letters). Specifically, low skilled readers were less likely to skip three-letter words when the foveal load was high (i.e., the target word was preceded by a low-frequency or low-predictability word).

While all these studies are informative and provide insight into the relationship between reading comprehension and eye movements, they are limited in that they measure reading comprehension as a whole and do not distinguish variation in the reading sub-skills hypothesized to comprise reading comprehension (i.e., word decoding and language comprehension). It should be noted that the Nelson-Denny test does measure vocabulary, however this was not reported as a separate component skill by previous researchers. Thus, the current experiment also measured vocabulary skills to investigate the impact this skill may have on eye movement patterns in tandem with the component skills from the SVR (i.e., decoding and language comprehension).

The component reading skills in the SVR have been significantly correlated with eye movement measures. For example, it appears decoding skills are correlated with eye movements such as fixation duration (Reichle, 2006) and saccade planning (Eden, Stein, Wood & Wood, 1994), and gaze duration appears to capture lexical activation time (Rayner, 1998; Rayner, Chace, Slattery, & Ashby, 2006). Barnes et al. (2017) investigated the relationship between the SVR component skills and eye movements during oral reading in low-skilled adult readers. Decoding, language comprehension, and reading comprehension were measured using offline tasks from the W*oodcock- Johnson III Diagnostic Reading Battery* (Schrank, Mather, & Woodcock, 2004). Participants were then asked to read passages aloud while several eye movement measures were tracked including reading fluency (words correct per minute), fixation duration, gaze duration, total reading time, initial landing position, saccade amplitude, skipping rate, proportion of regressive saccades, and refixations (gaze count). Fixation duration and gaze duration were significantly and negatively correlated with all the offline reading measures, indicating that better skill in decoding, language comprehension, and reading comprehension were all associated with shorter fixation durations and gaze durations. Total reading time was also significantly and negatively correlated with decoding and reading comprehension. The researchers also investigated whether eye movement variables could account for unique variance in reading comprehension above and beyond the SVR components (decoding and language comprehension. They found that the measure of lexical activation time (gaze durations and regressive saccades) accounted for unique variance in reading comprehension, and further, gaze durations accounted for variance shared with decoding skills. Similar results were reported in an earlier study by Barnes and Kim (2016) where they found that gaze durations accounted for unique variance in reading comprehension above and beyond decoding and language comprehension in children and low skilled adult readers. Barnes and her colleagues concluded that since the measure of gaze durations also include first fixation durations and refixations, it can be considered a measure of early word identification and lexical activation in reading. Therefore, gaze durations may reflect some degree of decoding skills, but during a task of word reading (i.e., reading comprehension tasks) this measure may also reflect other skills associated with word identification such as vocabulary knowledge.

Given evidence supporting the Eye-Mind Link Hypothesis indicating that cognitive processes may be revealed by eye movements and the number of individual differences in eye movement patterns across readers, it follows that the component skills involved in the SVR (decoding, language comprehension and reading comprehension) may also be reflected by specific eye movement patterns. Thus, eye movement patterns may provide a more sensitive online measure of the component skills involved in the SVR model and be predictive of reading comprehension. To our knowledge, very few studies have specifically investigated the relationship between the component skills from the SVR model and eye movement patterns (though see e.g., Barnes, Kim, Tighe & Vorstius, 2017). However, if the SVR postulates to account for all variation in reading comprehension, then the eye movement patterns that reflect these component skills should therefore also account for all the variation in reading comprehension even for skilled readers. Thus, the current experiment seeks to bridge this gap by investigating reading abilities in a sample of skilled readers of English, as predictors of eye movement patterns in sentence reading.

Many studies have investigated text level factors and individual differences that affect eye movement measures separately, but few have examined these factors in tandem. The current experiment aimed to bridge this gap in skilled adult readers to investigate the extent to which word recognition processes (i.e., measured by length and frequency effects) are related to individual differences in the component skills involved in the SVR. The results of this experiment also served as a baseline with which comparisons were made between skilled readers of English and dyslexic and bilingual readers in the subsequent thesis Chapters.

2.3.2 Experiment 2: Eye Movement Patterns in an Inconsistent Orthography

Reading involves planning and executing patterns of eye movements to aid in swift and accurate comprehension of a text (Rayner, 2009). Reading strategies may, therefore, also be assessed through the tracking of eye movements, and analysis of eye movement patterns. These strategies, and thus eye movement patterns, may be affected by the stage of development a reader is in, as well as the consistency of the orthography. The current experiment aimed to address two main research questions:

1.) How do eye movement patterns characterize the time-course of skilled English monolingual reading?

2.) What is the extent to which these eye movement measures reflect the component skills included in the SVR model (i.e., decoding and language comprehension; (Gough & Tunmer, 1986; Hoover & Gough, 1990) for the same sample of participants?

To address the first question, the current experiment sought to produce an on-line record of reading strategies measured by eye movements employed by skilled monolingual English participants as they read full sentences while being instructed to also extract meaning.

Previous research has generally measured reading performance using only single-words in isolation, with few studies examining full parts of sentences with multiple words, although correlations between eye movement measures during different reading tasks has demonstrated that eye movement patterns remain consistent (e.g., Krieber, et al., 2016). While single-word reading is useful to investigate the process of activation of the lexicon without the help of contextual clues, it will not reveal a full natural reading process. Further, as mentioned previously, during a fixation, a reader processes information both in the fovea and parafoveally, the latter of which may aid in integrating orthographic and phonological processing (Drieghe, Rayner & Pollatsek 2005; Gordon, Plummer & Choi, 2013; Rayner, 1998; Rayner, 2009). Thus, using full sentences will provide a more realistic view of natural reading processes and allow better identification of the sources of changes in performance throughout text reading. For these reasons, the current experiment investigated both sentence-level (global) and word-level (local) eye movement processes. Both early and late eye movements were of particular interest. As with the measures from *Experiment 1*, the measures from the current experiment also served as data that will be compared to Spanish-English bilinguals and dyslexic readers in subsequent Chapters of this thesis.

The second research question was addressed by comparing these eye movement measures with the component skill measures from the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990) that were measured offline in *Experiment 1*. This question is particularly important for two reasons. The first being that if individual skills are found to widely affect variance in eye movement patterns, then these skills must always be considered to draw meaningful conclusions in eye-tracking research. Second, the coordination between eye movement patterns and the individual differences in component skills from the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990) may provide further support for this model as well as an objective way to measure the component skills. These analyses provide a further understanding of developed component skills and their relationship to cognitive processes involved in reading as measured by eye movement strategies.

2.3.4 The Pilot Experiment

A pilot experiment was conducted to collect preliminary eye-tracking data from a sample of participants while they read short sentences for meaning. The aim of the pilot was to evaluate the feasibility of the proposed methodology. Specifically, running the current pilot experiment allowed trouble-shooting the eye-tracking equipment and experimental materials, evaluation of the amount of time spent on the experiment, a determination of whether the chosen eye-movement measures (first fixation duration, gaze duration, go-past time, and total reading time) and the created stimuli elicited responses robust enough to be analysed. Also evaluated, was the extent to which this protocol and analyses answered the proposed research questions. After preliminary data was collected, the data were critically analysed to determine whether the current design detected differences in eye movement patterns between participants who are reading sentences for meaning and adjusted the protocol as needed.

2.3.5 Method

2.3.5.1 Participants

The sample consisted of 10 native-English participants without dyslexia (7 females, 3 male, M_{age} = 18.70) attending Brunel University London.

2.3.5.2 Measures and Materials

As was measured in the behavioural experiment (*Experiment 1*), subtests from the *Woodcock-Muñoz Language Survey III* (WMLS III; Woodcock, Alcarado, & Ruef, 2017) were used to assess participants' language skills, which are vocabulary knowledge – Picture Vocabulary, decoding skills – Letter-Word Identification, language comprehension – Verbal Analogies and reading comprehension – Passage Comprehension. The aim of included these measures was to address the research question outlined above concerning the extent to which the chosen eye movement measures reflect the component skills included in the SVR model (i.e., decoding and language comprehension; (Gough & Tunmer, 1986; Hoover & Gough, 1990)).

Sentence Stimuli

The stimuli for the pilot experiment included 140 total sentences (70 experimental, and 70 filler) and 33 comprehension questions. The filler items were included for all English monolingual participants because of the future planned comparisons with bilingual participants. The bilingual participants read a set of sentences in both their native and second language, therefore English monolinguals needed to read the same number of sentences to control for any effects of fatigue.

The sentences contained 12-15 words (*M* = 13.67) and were coded and matched for total number of words, word length, and word frequency. Frequency information was obtained via the Zipf scale (van Heuven, Mandera, Keuleers, and Brysbaert, 2014) obtained from the norms from the SUBTLEX-UK database (van Heuven, Mandera, Keuleers, & Brysbaert, 2014). The Zipf scale is a logarithmic scale in which words are calculated as log10 (frequency per billion words). In this scale, frequency scores range from 1 (1 per 100 million words) to 6 (1000 per million words) with the lower half of the scale (1-3) representing low-frequency words and the upper half (4-6), high-frequency words. The sentences constructed for the current experiment were a variety of lexically simple, short compound sentences, with either one or two independent clauses or including a dependent clause (see Appendix 5).

50 pairs of high-frequency and low-frequency words were chosen from these sentences as targets for the word-level analyses. Targets were embedded in the sentences participants read. This total excluded first and final words in the sentences; function, punctuated, and repeated words; proper nouns; and words with cross-language orthographic overlap, such as cognates and interlingual homographs (e.g., Miellet et al., 2007; Pollatsek et al., 2006; Whitford & Titone, 2012; 2014).

Again, frequency information for the targets was again measured via the Zipf scale (van Heuven, Mandera, Keuleers, and Brysbaert, 2014) obtained from the norms from the SUBTLEX-UK database. High-frequency targets had a mean Zipf of (5.24) and low-frequency targets had a Zipf of (2.89) and were matched for length. The high-frequency and low-frequency words were further divided into short and long words. There were an equal number of short words consisting of 3-5 letters (*M* = 4.71) and long words consisting of 6-11 letters (*M* = 8.99).

A set of critical TRUE–FALSE comprehension questions appearing after 50% of the stimuli were used to ensure that participants processed the meaning of the sentences and were paying attention. Data was only included from the participants who answered correctly on at least 80% of the comprehension questions.

2.3.5.3 Apparatus

Participants' eye-movements were recorded using an Eyelink 1000 (SR Research, 2010) Desktop Mount eye-tracking device at a sampling rate of 2000 Hz and spatial resolution of less than 0.02-degree visual angle, which recorded the position of the reader's eye every half millisecond. Participants were seated 60 cm away from a monitor (with a refresh rate of 100 Hz) on which the stimuli were presented using E-Prime software (Psychology Software Tools, Pittsburgh, PA).

Head movements were minimized with a combination chin and headrest. The tracker's accuracy was checked, and a ten-point calibration was conducted prior to the initial presentation of stimuli and a single fixation calibration was conducted before each item. Eye-movements were recorded from the right eye only, which is common practice recommended by Rayner and Slattery (2010). Text was presented in black 14-point Times New Roman font on a dark grey background.

2.3.5.4 Procedure

The experiment lasted approximately one hour and a quarter (twenty minutes for the WMLS III tasks and fifty-five minutes for the eye-tracking task) and was completed in a laboratory at Brunel University London's campus. Upon entering the lab, participants were asked to read a participant information sheet (see Appendix 2a) and complete a subsequent written consent form (see Appendix 2b) where participants were informed that they were able to withdraw from the experiment at any time without having to give reason. Participants also completed a demographics and language history questionnaire (see Appendix 3).

Administration of the WMLS followed the standard procedure as outlined in the testing manual. The experimenter began each subtest by reading the instructions and administering two practice items to ensure that the participant understood the directions. Testing then began with an age-appropriate item (since all participants were aged 18 or older and in university, they all began with the same item set). First, a base level was established, if one or more items of the first set of six were incorrect, testing continued with the previous set until all items in a set of six were correct. The item sets prior to the base level were counted as correct responses. Testing then continued with the subsequent sets until six items in a row were answered incorrectly, or when the last item was administered. The number of correct responses was recorded and used for analysis.

Next, participants completed the eye-tracking portion of the experiment. Participants read a total of 140 total sentences (70 experimental, and 70 filler) and 33 comprehension questions. Five additional sentences and comprehension questions were constructed as practice items and presented to familiarize participants with the experimental setup and were not used in the subsequent analyses. Participants were instructed to read sentences silently on a computer screen for comprehension while their eye movements were monitored. Participants were told to read as they normally would and to press a button when they finished reading each sentence. This self-paced methodology has been used in previous eye tracking experiments (e.g., Egan et al., 2019). Sentences and comprehension questions were presented as single lines of text (with standard punctuation and capitalization).

All sentences were presented in counterbalanced order to participants. Participants read silently as several studies have reported that reading silently may have different underlying processes than reading aloud. For example, in experiments that investigate code-switching (when a bilingual switches from one language to another) silent reading is generally faster than reading aloud (Kolers, 1996; Macizo, Bajo & Paolieri, 2012; Ahn et al., 2020). Macizo et al. (2012) suggested that language production and silent comprehension may rely on different cognitive mechanisms. For example, evidence suggests that language production may involve inhibitory control where the speaker must choose some words while inhibiting others to convey meaning. Comprehension involves reading words that are already provided and thus, may not require inhibition. Therefore, in this experiment it was decided to measure the most naturalistic reading comprehension processes as possible thus, the silent reading method was employed.

To ensure participants were paying attention to the sentences and reading for meaning, reading comprehension was assessed through a set of critical TRUE–FALSE questions appearing on 50% of the experimental sentences. Participants were instructed to respond "TRUE" or "FALSE" using the appropriate buttons on a control pad. Participants were given five practice trials to become familiar with the procedure before reading the experimental sentences. Rest breaks were provided as needed.

After participants finished testing, they were given the participant information sheet to provide them with contract details should there be any further questions or problems.

2.3.6 Results

Mean comprehension accuracy was 92%, indicating that participants read the sentences for meaning.

2.3.6.1 Feasibility Measures

The first feasibility measure examined in the current pilot experiment was the amount of time participants took to complete the experiment. The average time spent on the experiment was approximately 78.62 minutes, (*SD* = 5.62).

2.3.6.2 Eye Movement Data

After eye-tracking data had been collected, a 2-stage cleaning procedure was completed to remove very short (< 80 ms) or very long fixations (> 1,000 ms) (Inhoff & Radach, 1998; Liversedge, Paterson, & Pickering, 1998). The duration in the first step was set at 80 ms with an angle of 1 degree to merge fixations shorter than 80 ms to the nearest fixations within one degree of visual angle. The second and third stages were left blank, and the final stage was set to remove any fixations outside of 80 ms to 1000 ms. Durations less than 80 ms or more than 1,000 ms are typically discarded as outliers in eye movement experiments (Inhoff & Radach, 1998; Liversedge, Paterson, & Pickering, 1998). Targets that received no fixation in first-pass reading were excluded from analyses for all measures of processing time. Total data loss was 10.70%.

Both global (i.e., sentence-level) and local (i.e., word-level) eye movement measures were examined (reviewed in Rayner, 1998, 2009; Rayner et al., 2012; Whitford et al., 2016). Our global measures which reflect processing difficulties, included total reading time, average fixation duration, average fixation count, and average regression. Local measures, which reflect processing difficulty for the included both early and late measures of reading. Early and late eye movement measures of reading were examined in this experiment to provide a complete picture of reading strategies (Rayner, 1998; Rayner, 2009). Early measures included first fixation duration and gaze duration. These measures are assumed to reflect initial lexical access. Late measures included go-past time and total reading time, which are assumed to reflect higher order processes such as semantic integration (Rayner, 1998; Kemper, Crow, & Kemtes, 2004; Rayner, 2009). Definitions for each of the above eye movement measures were taken from Liversedge, Paterson, and Pickering (1998), and are provided in *Table 8* (above) for reference.

Sentence-Level Measures for Pilot Sample

We first conducted an analysis on the global eye movement measures calculated from the sentence as a whole. Descriptive statistics from each variable were calculated to determine whether results from our sample were typical of the average adult English reader, as reported by previous literature (e.g., Rayner, 1998, 2009; Rayner et al., 2012; Whitford et al., 2016). Mean eye-movement measures are shown in *Table 9*.

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Table 9. Mean Eye-Movement Measures Across Sentences for Pilot Sample

Measure	Fixation Count	Backward Saccade Count	Total Reading Time (ms)	Average Fixation Duration (ms)
Mean (SD)	11.29 (3.22)	4.72 (0.94)	3304.16 (697.05)	201.57 (21.93)
Range	6.85 – 15.54	3.00 – 6.39	1911.23 – 4242.9	196.75 – 229.68

Word-Level Measures for Pilot Sample

Next, a repeated measures ANOVA was conducted for each of the local eye movement measures (First fixation duration, gaze duration, go-past time, and total reading time) with Bonferroni corrected alpha of .013 to investigate the effects of length and frequency.

Table 10. Mean Eye-Movement Measures for Frequency x Length for Pilot Sample

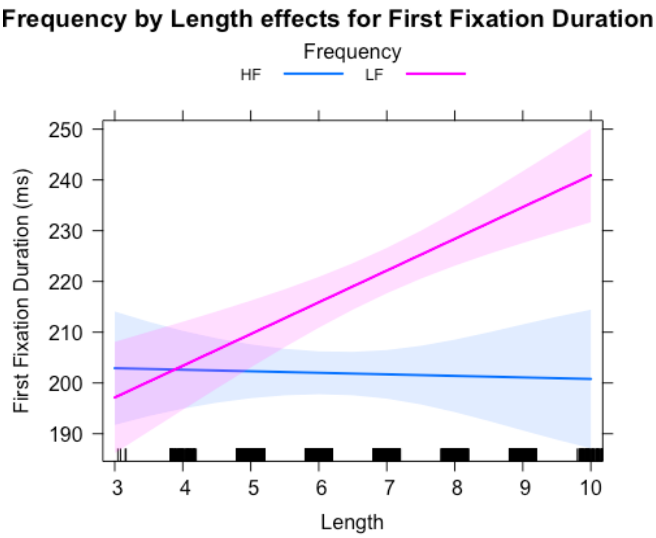
Measure Mean (SD)	First Fixation Duration	Gaze Duration	Go-Past Times	Total Reading Times
HF_Short Words	207.26 (80.25)	239.07 (117.72)	212.93 (98.34)	340.05 (361.46)
LF_Short Words	199.54 (83.78)	237.17 (131.25)	204.17 (84.56)	293.92 (252.25)
HF_Long Words	192.78 (79.07)	220.63 (111.98)	209.95 (131.15)	343.95 (334.70)
LF_Long Words	227.78 (90.88)	282.65 (144.68)	269.58 (165.59)	387.76 (360.44)

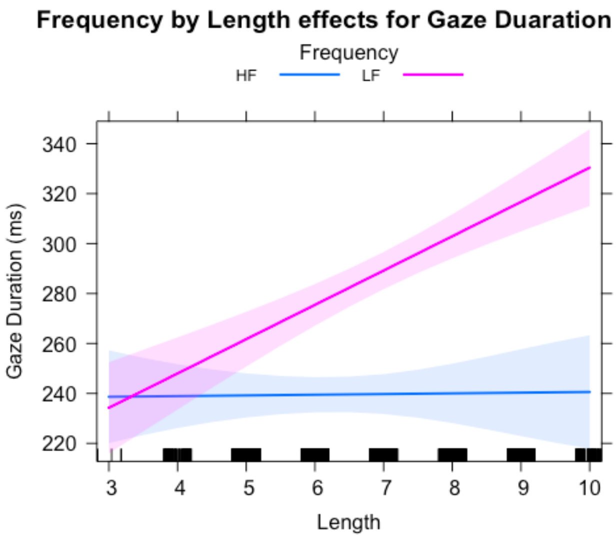
There was a significant effect of frequency for all the eye movement measures except total reading time. Specifically, as seen in Table 10, shorter first fixation durations $F(1,9) = 11.49$, $p < .001$, ($M_{HF} = 197.41$, $SD_{HF} = 79.64$; $M_{LF} = 218.70$, $SD_{LF} = 89.50$), gaze durations $F(1,9) = 19.63$, $p < .001$, ($M_{HF} = 226.53$, $SD_{HF} = 113.98$; $M_{LF} = 268.02$, $SD_{LF} = 141.80$) go-past times

$F(1,9) = 6.78$, $p < .001$, ($M_{HF} = 210.86$, $SD_{HF} = 121.86$; $M_{LF} = 250.08$, $SD_{LF} = 148.87$) were exhibited for frequent compared to infrequent words. There was no significant difference between high-frequency ($M = 342.64$, $SD = 343.63$) and low-frequency words ($M = 357.93$, $SD = 332.43$) for total reading times ($F(1,9) = 0.62$, $p = .235$).

There was also a significant main effect of length for all eye movement measures. Specifically, as seen in Table 10, shorter first fixation durations $F(1,9) = 5.51$, $p < .01$, ($M_{short} = 204.20$, $SD_{short} = 81.59$; $M_{long} = 206.61$, $SD_{long} = 85.58$), gaze durations $F(1,9) = 8.39$, $p < .001$, ($M_{short} = 238.32$, $SD_{short} = 123.01$; Long; $M_{long} = 245.14$, $SD_{long} = 129.35$) but not go-past times ($F(1,9) = 3.94$, $p = .024$), (Short; $M_{short} = 209.92$, $SD_{short} = 93.49$; Long; $M_{long} = 230.88$, $SD_{long} = 146.62$) and total reading time $F(1,9) = 6.01$, $p < .01$, (Short; $M_{short} = 322.50$, $SD_{short} = 324.58$; Long; $M_{long} = 361.54$, $SD_{long} = 345.63$) were exhibited for short compared to long words.

There was also a significant interaction between length and frequency for all of the eye movement measures except total reading times ($F(1,9) = .29$, $p = .372$). Specifically, as seen in Figures 8-11, there was a significant interaction for first fixation durations $F(1,9) = 9.26$, $p < .001$, gaze durations $F(1,9) = 17.84$, $p < .001$, second pass reading times $F(1,9) = 8.89$, $p < .001$.





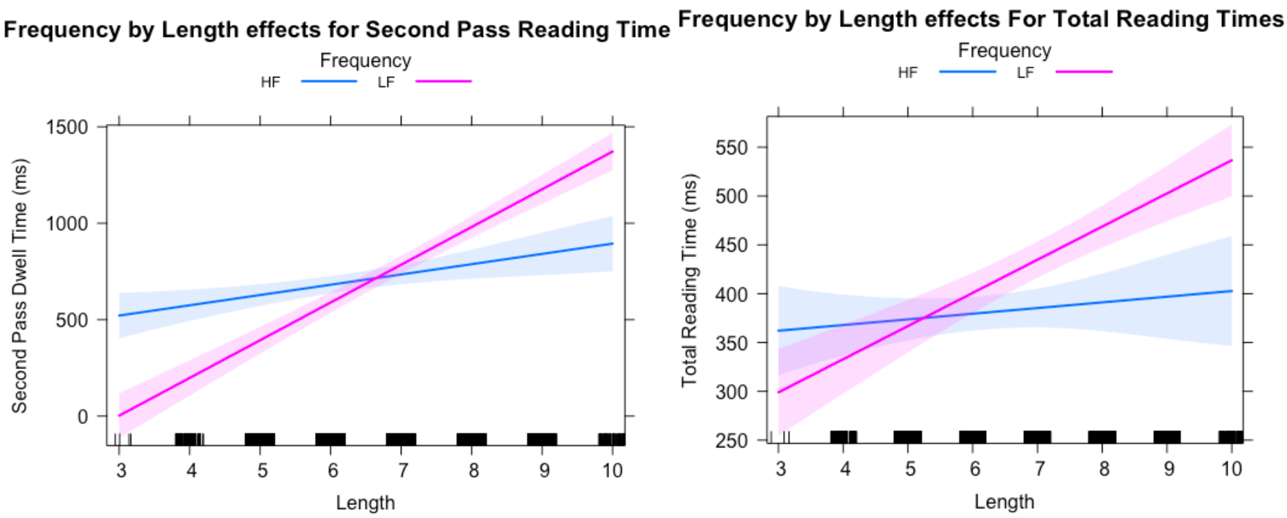


Figure 8, 9, 10, and 11. Length by Frequency Effects on Eye Movement Measures for Pilot Sample

2.3.6.3 WMLS III Measures for Pilot Sample

The raw scores for each of the four subtests were also measured in the pilot sample to test them against the eye-tracking measures. Raw scores are tabulated in Table 11.

Table 11. WMLS III Subtest Raw Scores for the Pilot Sample

Subtest	N Items	Range	Mean	SD
Language Comprehension	39	23 – 35	30.45	4.30
Vocabulary Knowledge	56	38 – 51	42.64	4.08
Decoding Skills	76	65 – 76	69.82	3.37
Reading Comprehension	52	40 – 50	45.18	3.54

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Next a series of correlations were computed between each of the WMLS III reading ability scores for this pilot sample. As demonstrated in Table 12, all correlations were significant and all $p < .001$.

Table 12. Correlations of Language Abilities for the Pilot Sample

	Language Comprehension	Vocabulary Knowledge	Decoding
Language Comprehension			
Vocabulary Knowledge	.72***		
Decoding	.78***	.89***	
Reading Comprehension	.85***	.83***	.93***

Notes: correlation is significant at the $p > .001$***

2.3.6.4 Correlations Between Eye Movement Patterns and Behavioural Measures for Pilot Sample

To test whether the scores from the WMLS III were related to eye movement patterns, a series of correlations between each eye movement measure and each language ability measure from the WMLS III have been conducted. Only significant correlations were reported with Bonferroni corrected alphas of .013.

Sentence-Level Measures for Pilot Sample

First, the language scores were correlated with the whole sentence eye movement scores (average fixation duration, backward saccade count, and total reading time). Only one significant negative correlation was found between vocabulary scores and average fixation duration $r(10) = -.64$, $p = .011$, indicating that as vocabulary scores increased, fixation durations were shorter.

Word-Level Measures for Pilot Sample

Next, the language ability scores and eye movements measured at the word-level (first fixation duration, gaze duration, go-past time, and total reading time) were correlated.

Language Comprehension: There were no significant correlations found between language comprehension and any of the eye movement measures.

Decoding: There were significant negative correlations between decoding scores and gaze duration for high-frequency short words $r(10) = -.66$, $p < .05$ indicating that as decoding scores increased, gaze durations for high-frequency short words decreased. There was also a significant negative relationship between decoding scores and gaze durations $r(10) = -.64$, $p < .01$ and total reading time $r(10) = -.61$, $p = .012$ for low-frequency short words, indicating that as decoding scores increased, total reading time and gaze durations for low-frequency short words decreased.

Vocabulary Knowledge: There were significant negative correlations between vocabulary scores and first fixation durations for high-frequency long words $r(10) = -.57$, $p < .001$. These results indicate that as vocabulary scores increased, first fixation durations for high-frequency long words decreased.

Reading Comprehension: There were significant negative correlations between reading comprehension scores and first fixation durations, $r(10) = -.65$, $p < .01$ for low-frequency short words indicating that as reading comprehension scores increased, first fixation durations for low-frequency short words decreased.

2.3.7 Interim Discussion for Pilot Sample

The current pilot experiment was conducted to test the feasibility of the proposed eye-tracking protocol and to identify potential problems or shortcomings. Participants spent an average of one hour and a quarter ($M = 78.62$ minutes, $SD = 5.62$) on the experiment in the initial protocol. To reach the target testing time of one hour, 40 sentences and 8 comprehension questions were removed from the task resulting in 100 total sentences (50 experimental, and 50 filler) and 25 comprehension questions. The resulting sentences still contained 12-15 words (M = 13.29). 40 of the 50 pairs of high and low-frequency targets were subsequently chosen from the remaining sentences. Again, frequency information for the targets was again measured via the Zipf scale (van Heuven, Mandera, Keuleers, and Brysbaert, 2014) obtained from the norms from the SUBTLEX-UK database. High-frequency targets had a mean Zipf of (5.86) and low-frequency targets had a Zipf of (2.37) and were matched for length. The high-frequency and low-frequency words were further divided into short and long words. There were an equal number of short words consisting of 3-5 letters (M = 4.32) and long words consisting of 6-11 letters (M = 8.82) and an independent samples t-test showed no significant difference for frequency between the long and short words ($t(80) = 0.849$, $p = .397$).

Rayner (1998) reported that eye movements during silent reading in English last about 200 – 250 ms, our sample showed fixations or 199.08 on average with a standard deviation of 21.93. Rayner (1998) also reported that around 10-15% of saccades are regressions. Our sample indicated the same. Results showed that the eye-tracking measures taken from the current sample were indeed typical of average English readers with similar characteristics (Rayner, 1998). Since the eye-movements measured in the current sample were comparable to those collected from previous studies, this indicates that the stimuli elicited responses can reliably be tested against the hypotheses in the subsequent experiment.

A few eye movement trends emerged from the pilot data. Specifically, the well-documented effects of word length and word frequency were replicated (e.g., see Rayner, 2009). The high-frequency short words had the fastest eye movements, and the low-frequency long words had the longest eye movements. Thus, it is reasonable to assume that the methods and analyses from this pilot experiment successfully captured eye-movement patterns that were reflective of reading comprehension and thus can be further explored in the main experiment.

Several eye movement measures also correlated significantly with the component skills from the SVR formula, indicating that these component skills may be reflected by eye-movement patterns. These relationships between eye-movement patterns and the component skills can therefore feasibly be further analysed in subsequent eye-tracking analyses. In particular, fixation duration measures, and gaze durations correlated with most of the component skills thus warranting further analysis in the main experiment if similar trends are found.

No significant issues were experienced with the rest of the protocol, or the eye-tracking equipment and software. Thus, no further alterations were made for the protocol in the following experiments.

2.3.8 The Main Experiment

2.3.8.1 Hypotheses

The overarching question that motivated the current experiment was if eye-movement can be more sensitive measures of the component skills from the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990) (e.g., decoding and language comprehension) and can predict reading comprehension. Examining the patterns of eye movement behaviour may lead to a better understanding of the relationship between specific eye movement measures and individual reading skills. However, several specific hypotheses were also addressed:

1. It was expected that monolingual English native readers without reading impairments would employ eye movement measures like those observed in skilled readers and that the well-documented effects of length and frequency would be found in this sample of readers (reviewed in Rayner, 1998, 2009; Rayner et al., 2012; Whitford et al., 2016). Specifically, like results from the pilot experiment, it was expected that there would be a main effect of length and frequency as well as an interaction for all

eye movement measures. These effects were expected based on the DRC model (Coltheart et al., 2001).

2. It was also expected that the SVR component skills (i.e., decoding, language comprehension, and reading comprehension) would correlate with eye movement patterns. For a population of skilled adult readers of an inconsistent orthography, it was expected that decoding skills would correlate with early eye movement measures of lexical access (e.g., first fixation duration and gaze durations) as well as fixation and saccade count since research has shown these eye movements may reflect phonological decoding processes (Kuperman & Van Dyke, 2011; Liversedge, Paterson, & Pickering, 1998; Rayner et al., 2006; Rayner, 1998; Rayner, 2009). In contrast, it was expected that language comprehension and reading comprehension would correlate with the late eye movement measures of lexical access (e.g., go-past times and total reading times) as well as sentence-level measures of total reading times since these eye movements may reflect higher order processing (Kuperman & Van Dyke, 2011; Liversedge, Paterson, & Pickering, 1998; Rayner et al., 2006; Rayner, 1998; Rayner, 2009). Since vocabulary knowledge was the strongest predictor of reading comprehension in the current sample of skilled readers of English, and since it is an important factor in building the lexicon, it was also expected that this skill should correlate with eye movement measures specifically for low-frequency words.

2.3.9 Methods

2.3.9.1 Participants

The same 52 participants from *Experiment 1* participated directly afterwards in the current experiment.

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2.3.9.2 Measures and Materials

The methods and materials were identical to those used in the above pilot experiment. The only difference was the number of sentence stimuli used (see interim discussion). In the current experiment participants read 100 sentences (50 experimental and 50 filler) and answered a total of 25 comprehension questions to ensure attentiveness.

2.3.9.3 Apparatus

The apparatus was identical to that used in the above pilot experiment.

2.3.9.4 Procedure

The procedure was identical to that described in the pilot study above. The only difference was the amount of time it took participants to complete the eye-tracking experiment. With the reduced number of stimuli, participants spent approximately 40 minutes completing the experiment.

2.3.10 Results

After eye-tracking data had been collected the same cleaning procedure from the pilot experiment was used to remove very short (< 80 ms) or very long fixations (> 1,000 ms) (Inhoff & Radach, 1998; Liversedge, Paterson, & Pickering, 1998). Targets that received no fixation in first-pass reading were excluded from analyses for all measures of processing time. Total data loss was 11.23%.

As in the pilot experiment, global eye movement measures (fixation and regression count, fixation duration, and total reading time) were calculated across the whole sentence. The local measures were calculated from long and short high-frequency and low-frequency words These measures included first fixation duration, gaze duration, go-past times and total fixation time (see Table 8 for the definitions of each of these measures).

The current experiment investigated eye movement patterns in native English monolingual readers while reading sentences for meaning in English. Before eye movement measures

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were analysed, the TRUE-FALSE critical comprehension scores for the sentences for each participant were calculated. All participants scored 80% or higher and thus no participant was excluded from analysis.

2.3.10.1 Sentence-Level Measures for Monolingual English Readers without Dyslexia

Means and standard deviations for each eye movement measure are tabulated in Table 13. These scores were calculated based on average scores across the entirety of each sentence.

Table 13. Mean Eye-Movement Measures Across Sentences for Monolingual English Readers without Dyslexia

Measure	Fixation Count	Average Fixation Duration (ms)	Regression Count	Total Reading Time (ms)
Mean (SD)	13.47 (2.99)	204.67 (19.58)	5.38 (1.39)	3510.65 (782.57)
Range	6.85 – 15.54	196.75 – 22968	3.00 – 6.39	1911.23 – 4242.9

2.3.10.2 Word-Level Measures for Monolingual English Readers without Dyslexia

To investigate word-level effects on eye movement strategies, a 2 (frequency: low vs high) x 2 (length: long vs short) repeated measures ANOVA was conducted for each of the eye movement measures (First fixation duration, gaze duration, go-past time, and total reading time) to investigate the effects of length and frequency with Bonferroni corrected alphas of .013.

Table 14. Mean Eye Movement Measures for Frequency x Length for Monolingual English Readers without Dyslexia

Measure Mean (SD)	First Fixation Duration	Gaze Duration	Go-Past Times	Total Reading Times

HF_Short Words	207.80 (29.29)	251.07 (48.04)	381.76 (112.13)	400.86 (127.44)
LF_Short Words	212.18 (36.15)	267.12 (69.13)	402.93 (131.17)	419.71 (132.59)
HF_Long Words	199.63 (21.64)	235.75 (39.97)	463.31 (133.98)	448.12 (174.34)
LF_Long Words	223.99 (29.07)	296.52 (56.81)	526.06 (194.84)	542.71 (148.43)

There was a significant main effect of frequency for all the eye movement measures. Specifically, as seen in Table 14, shorter first fixation durations $F(1,51) = 15.07$, $p < .001$, gaze durations $F(1,51) = 35.28$, $p < .001$, go-past reading times $F(1,51) = 22.30$, $p < .001$, and total reading times $F(1,51) = 9.37$, $p < .001$, were exhibited for high-frequency compared to infrequent words.

There was also a significant main effect of length for the late eye movement measures. Specifically, as seen in Table 14, shorter, go-past times $F(1,51) = 9.95$, $p < .01$, and total reading time $F(1,51) = 21.07$, $p < .001$, were exhibited for short compared to long words. There was no significant difference in first fixation durations ($F(1,51) = .356$, $p = .533$), or gaze durations ($F(1,51) = 2.61$, $p = .112$), between short and long words.

There was also a significant interaction between length and frequency for all eye movement measures. Specifically, as seen in Figures 12-15, there was a significant interaction for first fixation durations $F(1,51) = 8.58$, $p < .01$, gaze durations $F(1,51) = 22.01$, $p < .001$, go-past times $F(1,51) = 8.54$, $p < .01$ but not for total reading times ($F(1,51) = 4.18$, $p = .045$). These interactions indicate that length effects were only found for low-frequency words but did not affect high-frequency words. Further, short words were not affected by frequency.

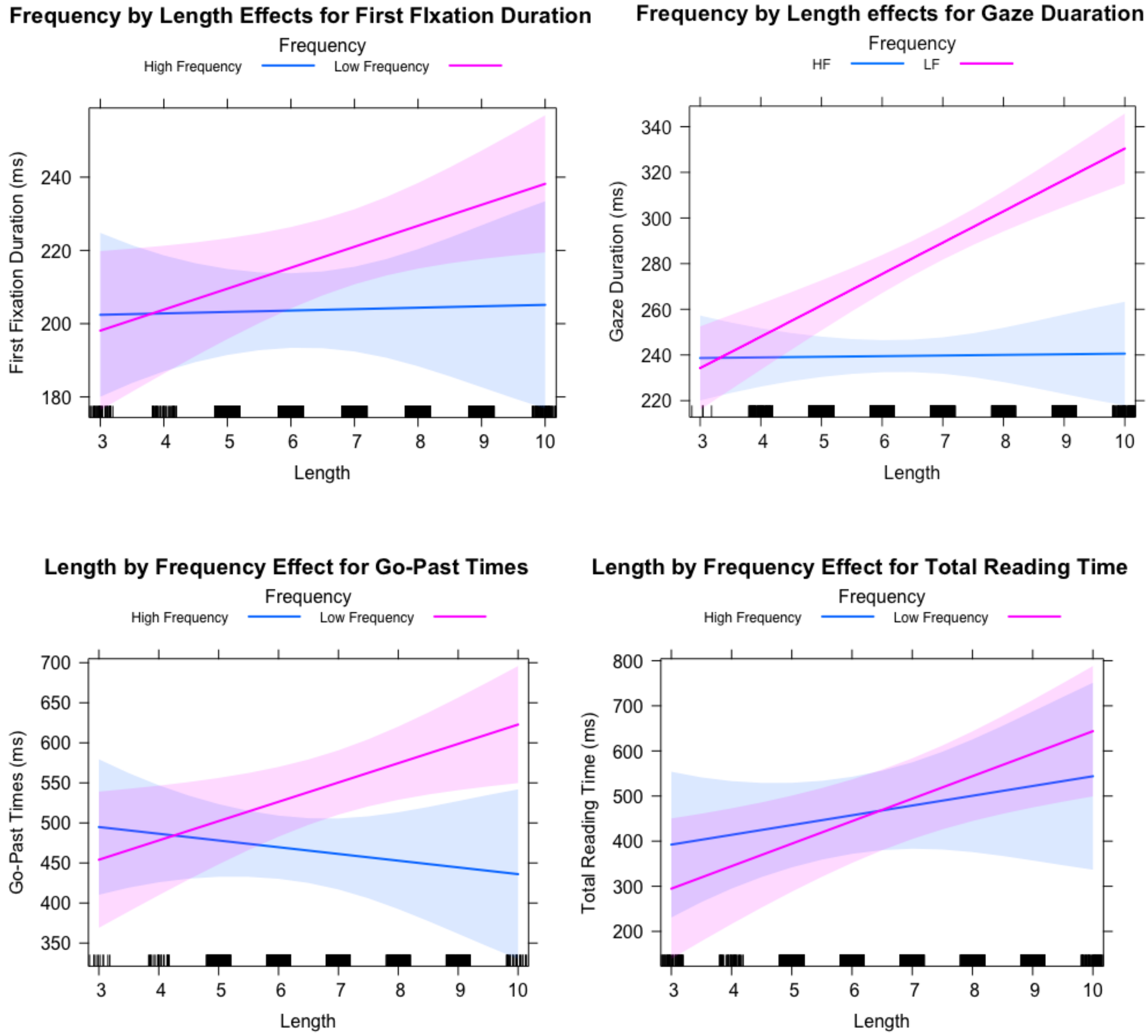

Figure 12, 13, 14, and 15. Frequency and Length effects on Eye Movement Measures for Monolingual English Readers without Dyslexia

2.3.10.3 Correlations Between Eye Movement Patterns and Behavioural Measures for Monolingual English Readers without Dyslexia

To test whether the scores from the WMLS III were related to eye movement patterns, a series of correlations between each eye movement measure and each language ability measure from the WMLS III have been conducted.

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Sentence-Level Measures for Monolingual English Readers without Dyslexia

First, we correlated each of the WMLS III scores with the whole sentence eye movement scores (average fixation duration, total fixation count, regression count, and total sentence reading time). Only significant correlations with a Bonferroni corrected alpha of 0.013 were reported.

Only one significant negative correlation was found between decoding and the number of fixations, $r(52) = -.34$, $p = .012$, indicating that as decoding scores increased, fixation count decreased.

Word-Level Measures for Monolingual English Readers without Dyslexia

Next, the language ability scores and eye movements measured at the word-level (first fixation duration, gaze duration, go-past time, and total reading time) were correlated. Only significant correlations with a Bonferroni corrected alpha of 0.003 were reported.

Language Comprehension: There were no significant correlations between language comprehension scores and word-level measures.

Decoding: There were significant negative correlations between decoding scores and gaze durations for low-frequency short words $r(52) = -.48$, $p < .001$ and for low-frequency long words $r(52) = -.52$, $p < .001$. These results indicate that as decoding scores increased, gaze durations low-frequency words decreased.

Vocabulary Knowledge: There were no significant correlations between vocabulary knowledge scores and word-level measures..

Reading Comprehension: There were significant negative correlations between reading comprehension scores gaze durations for low-frequency long words $r(52) = -.50$, $p < .001$ indicating that as reading comprehension scores increased, gaze for low-frequency long words decreased.

2.3.11 Discussion

The goal of *Experiment 2* was to measure reading strategies of skilled readers as indexed by eye movements and to compare these with measured reading abilities as described in the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990) measured in *Experiment 1* (Chapter-2). Results indicated that the current sample of skilled readers of English exhibited eye movements that were in ranges typically reported (for a review see Rayner, 1998; 2009). All eye movement measures were found to be affected by word frequency while late eye movement measures were influenced by word length. The component skills from the SVR and also vocabulary knowledge were found to correlate with both sentence-level and word-level eye movement measures, however, early eye movements of reading were best at predicting reading comprehension in the current sample of skilled readers of English. These results will be discussed in further detail below.

2.3.11.1 Eye Movement Strategies of Skilled English Readers

Sentence-Level Measures of Monolingual English Readers without Dyslexia

Sentence-level measures were analysed from average reading strategies across the sentences as a whole. Fixation count, fixation duration, regression count, and average total reading time were analysed. This analysis was mainly conducted to get a general baseline of native-English reading strategies and to ensure they did not appear to differ from findings reported in the literature.

The results from sentence-level analyses indicated that the current sample exhibited eye movements typically reported across the literature (for reviews see Rayner, 1998; 2009). Average fixation durations in the current sample (204.67 ms) were within the range typically observed in skilled adult readers' (200–250 ms; Rayner, 1998; Rayner et al., 2006; Rayner et al.,, 1989). Since the sentences contained an average of 13.67 words, participants exhibited an average of 0.99 fixations per word, and 0.39 regressions per word. Similarly, Blythe et al. (2009) reported an average of 10.3 fixations and 2.4 regressions for sentences that averaged between six and nine words equating to roughly 1.37 fixations and 0.32 regressions per word for adult readers during normal sentence reading (no average word count was reported). The proportion of regressive saccades to total saccades in the current sample was 18%, which was slightly higher than the average of 10%-15% cited by Rayner (1998) from a review of various studies. However, Rayner (1978b) also demonstrated that this eye movement measure can vary considerably even in skilled readers from as low as 1% to as high as 20%. Further, the current observation of 18% was also a much smaller proportion of saccades than those that have been reported for low-skilled adult readers (e.g., 35% in Barnes & Kim, 2016; 30% in Barnes, Kim, Tighe & Vorstius, 2017) or Grade-6 students (19%; Sovik, Arntzen, & Samuelson, 2000). Given that each of these eye movement measures fall within the normal ranges typically reported in eye-tracking research, it was determined that these averages would serve as a reliable baseline for further comparisons in age-matched readers with dyslexia and bilingual readers (Chapters 3-5).

Word-Level Measures of Monolingual English Readers without Dyslexia

The word-level measures were analysed in terms of length and frequency. The current experiment expected to find both length and frequency effects for all eye movement measures (Hypothesis-1).

Previous research has reported the robust finding that low-frequency words are less likely to be skipped and are fixated upon longer than high-frequency words (Hyönä & Olson 1995; Inhoff & Rayner 1986; Just & Carpenter 1980; Rayner & Duffy 1986; Rayner & Raney 1996; Rayner et al., 1996; 1998; Vitu et al., 2001), indicating that low-frequency words are processed more slowly and effortfully than high-frequency words in English readers. As expected, all the eye movement measures were sensitive to frequency effects. Both early and late eye movement measures of reading were shorter for high-frequency than low-frequency words. However, length x frequency interactions indicated that only long words were affected by frequency, and only low-frequency words were affected by length. These results suggest that words that are lower in frequency may require additional early lexical processing time and refixation time since such words are less familiar to readers than high-frequency words. The observation of frequency effects in skilled readers of English in early measures of reading is consistent with results from previous literature that reported frequency effects in early eye movement measures of reading (e.g., Ashby, Rayner & Clifton, 2005; Blythe et al., 2009; Inhoff and Rayner 1986; Just & Carpenter,1980; Rayner & Duffy, 1986).

These findings can be interpreted within the DRC model (Coltheart, Rastle, Perry, Langdon & Ziegler, 2001), which purports that reading can be accessed either via a sub-lexical decoding route, or a slower lexical route. Early eye movement measures which reflect early lexical access may be sensitive to frequency effects since low-frequency words may slow reading via the sub-lexical route once the lexical route fails to find a reliable match in the lexicon. However since the sub-lexical route is notoriously unreliable in English, this may have affected the early eye movement measures associated with phonological processing and decoding. These early measures may not have been able to resolve the discrepancy in the current sample of readers, and thus, later measures of lexical access may have also been slowed to allow for conflict resolution. Specifically, the go-past eye movement measure may reflect the cost of overcoming some difficulty with the first-pass reading time since it includes the time the eyes spent in the first-pass reading as well as second-pass readings (Clifton, Stuab & Rayner, 2007). Total reading time reflects all first pass and second pass measures and thus would have been slowed as well.

In contrast, results demonstrated that only the late eye movement measures of reading (go-past times and total reading times) were sensitive to length effects. Specifically, go-past times and total reading times were longer for long vs short words. However, length x frequency interactions indicated that the length effect was only found for low-frequency words. The early eye movement measures of reading did not significantly differ between short and long words in the current sample. Thus, for the current sample, it appears as though the time-course of frequency effects differ from that of length effects. These findings agree with previous research reports that effects of length appear to impact late stages of reading for readers of English. For instance, Rayner, Sereno, and Raney (1996) found that total reading time increased as word length increased and the probability of re-fixating the word (i.e., making more than one fixation on the word) increased with word length. Hyona and Olsen (1995), and later Joseph and colleagues (2013) did not find length effects for first fixation durations, but they did find them for gaze durations and second pass reading times. Likewise, Juhaz and Rayner (2003) did not find length effects for first fixation durations, and only found the effects for gaze durations and total fixation durations (similar to total reading times). However, the authors reasoned that the effect of word length on gaze duration was likely due to the higher refixation probability associated with longer words. To review, the gaze duration measure is the sum of all fixations on the word during first-pass reading, which includes first fixations during the first-pass, but also refixations that are made before the eyes leave the target for the first time. These refixations are sometimes argued to reflect later measures of reading (e.g., Rau et al., 2015; Reichle et al., 1998). While refixations within gaze durations were not measured in the current experiment, it is reasonable to conclude that there may not have been enough refixations to elicit an effect of length.

The time-course of length and frequency effects in the current sample may be interpreted in terms of the DRC model of reading (Coltheart et al., 2001) where frequent words are more readily available in the lexicon because they are read more often and can more easily be accessed by the faster lexical route. When the lexical route fails to find a reliable match, the slower sub-lexical procedure is used to decode the word. The results from the current sample indicate that early measures of lexical access (first fixation duration and gaze duration) were only affected by word frequency. These eye movement measures reflect initial lexical access particularly to the phonological properties of the word, and may rely on decoding skills (Pagán, Blythe & Liversedge, 2021; Rayner et al., 1998; Rayner et al., 2003; Sparrow & Miellet, 2002; Slattery, Pollatsek & Rayner, 2006). Thus, it makes sense that eye movements which reflect decoding procedures would be affected by low-frequency words. Similarly, the Lexical Quality Hypothesis (Perfetti & Hart, 2002) argues that high-frequency words have a high-quality representation in the lexicon and thus are more easily recognized. In contrast, representations in the lexicon may not be available for low-frequency words and the slower sub-lexical procedure must be used to process these words, slowing recognition and comprehension.

The sub-lexical procedure is also affected by length. In this case, longer words will take longer to decode than short words. However, given that skilled readers of English may not rely on a small-unit decoding process (Rau et al., 2015; Ziegler & Goswami, 2005), it makes sense that length effects may not interfere with eye movements that reflect initial lexical access and phonological processing, but instead affect second-pass measures.

The interaction of length and frequency effects also suggested that the length effect was only found for low-frequency words. Given that the sub-lexical route may not always be reliable for English readers, English readers may attempt to abandon the sub-lexical procedure to make use of the lexical route which will be slowed when matches are not easily found. Thus, slowing late processes of lexical access rather than early ones. Further, the language comprehension scores of the current sample of skilled readers were a better predictor of reading comprehension than decoding, it makes sense that the eye movement measures of higher order reading processes would be more variable and more sensitive to length effects.

2.3.11.2 Correlations between Eye Movements measures of Skilled English Readers and the Simple View of Reading Component Skills

To investigate whether eye movement strategies might be related to the component skills i.e., decoding, language comprehension, and reading comprehension, described in the SVR

(Gough & Tunmer, 1986; Hoover & Gough, 1990), these eye movement measures were correlated with the abilities measured in *Experiment 1*. The SVR posits that a reader's decoding skills (D) and language comprehension abilities (LC) are strong predictors of Reading Comprehension (RC). According to the SVR, decoding skills are defined as "efficient word recognition" (Hoover & Gough, 1990) as well word pronunciations from letter-sound (grapheme-phoneme conversion) knowledge (i.e., a sub-lexical reading skill) while language comprehension skills are defined as the ability to derive meaning from lexical information by employing the use of vocabulary, grammar, and semantic knowledge (Catts, Adlof, & Weismer, 2006). For a population of skilled adult readers of an inconsistent orthography, it was expected (i.e., Hypothesis-2), that decoding skills would correlate with early eye movement measures of lexical access (e.g., first fixation duration and gaze durations) as well as fixation and saccade count since research has shown these eye movements may reflect phonological decoding processes (Kuperman & Van Dyke, 2011; Liversedge, Paterson, & Pickering, 1998; Rayner, Chace, Slattery & Ashby, 2006; Rayner, 1998; Rayner, 2009). In contrast, it was expected that language comprehension and reading comprehension would correlate with the late eye movement measures of lexical access (e.g., go-past times and total reading times) as well as sentence-level measures of total reading times since these eye movements may reflect higher order processing (Kuperman & Van Dyke, 2011; Liversedge, Paterson, & Pickering, 1998; Rayner, Chace, Slattery & Ashby, 2006; Rayner, 1998; Rayner, 2009). Since vocabulary knowledge was the strongest predictor of reading comprehension in the current sample of skilled readers of English, and since it is an important factor in building the lexicon, it was also expected that this skill should correlate with eye movement measures specifically for low-frequency words.

Sentence-Level Measures of Monolingual English Readers without Dyslexia

Results found that only decoding scores measured in *Experiment 1* significantly correlated with any of the global eye movement measures that were measured across the whole sentence. Specifically, decoding scores were negatively correlated with total average fixation counts. Thus, higher decoding scores were associated with fewer fixations. These findings make sense given that fixations and saccades are thought to reflect decoding reading strategies (Rayner, 1998; Rayner et al., 2006). Decoding is assumed to be reflected by eye movement measures such as total fixation count according to previous research (Rayner, 1998, Rayner, 2009; Liversedge, Paterson, & Pickering, 1998, Korneev, Matveevn, & Akhutina, 2020). The current experiment supports this contention, at least with skilled readers of English.

Language comprehension scores, reading comprehension scores and vocabulary scores were not correlated with any of these global reading measurements. It was expected that language comprehension might correlate with total reading time since language comprehension has been found to be related to reading speed in previous research (e.g., Jackson, 2005; Katzir et al., 2006). However, reading speed is typically assessed with tasks that involve more complex reading material (e.g., pseudowords or passages) than simple sentences. Thus, perhaps language comprehension may not be associated with reading speed across full simple sentences that are not meant to be challenging.

Word-Level Measures of Monolingual English Readers without Dyslexia

As expected, there were significant negative correlations between decoding scores and early measures of reading (i.e., gaze duration) for all low-frequency words, both short and long, indicating that as decoding scores increased, gaze durations were shorter for all low-frequency words. These results make sense given that early measures of reading are thought to reflect early lexical access such as phonological processing (Rayner, 1998; Rayner, Chace, Slattery, & Ashby, 2006). Thus, better decoding skills may lead to faster and more efficient early lexical processing particularly when confronted with low-frequency words.

Further, gaze durations were also particularly sensitive to frequency effects; thus, better decoding skills may lead to faster early lexical access especially for low-frequency words. Presumably better decoders may detect low-frequency words faster in early stages of reading and may deploy efficient late eye movements to lexically processes these words. Such results are consistent with several studies reporting that more skilled readers are more efficient at processing low-frequency words compared to poorer readers in eye-tracking measures (e.g., Ashby et al., 2005; Hawelka et al., 2010). Similarly, Kuperman and Van Dyke (2011) found that word identification scores reliably predicted both early (i.e., first fixation position, first fixation duration, single fixation duration and gaze duration) and late-stage eye movements (i.e., go-past times, second pass reading times, and total reading times) and mediated the relationship between word-level predictors (e.g., length and frequency) and eye movement measures. Results from the current experiment however did not show a relationship between decoding scores and the late eye movement measures. The difference between the current results and those of Kuperman and Van Dyke (2011) may stem from participant characteristics as they were adults that specifically were not college-bound, while participants in the current sample were enrolled in a university. Thus, there may have been differences in patterns of late eye movement measures due to a slightly higher level of word identification skills in the current sample.

Neither language comprehension scores nor vocabulary scores significantly correlated with any of the eye-movement measures. These results were unexpected given that in *Experiment 1*, decoding only accounted for 21.6% of the variance in reading comprehension while language comprehension accounted for 41.5% and vocabulary accounted for 47%. Since language comprehension scores and vocabulary were better predictors than decoding of reading comprehension, it was expected that they may correlate with the eye movements associated with late measures of reading since these eye movement measures reflect higher order reading processes and some difficulty with the text. Further, Barnes et al. (2017) found that language comprehension significantly correlated with first fixation durations and gaze durations in a sample of low-skilled adult readers in an oral language task. However, there are several differences between their study and the current experiment that may have resulted in different patterns. Specifically, the current sample were skilled adult readers who completed a silent reading task. For these reasons, there may have been distinct differences in eye movement patterns between these two tasks and samples. It is possible that the current eye movement measures fail to reflect this particular skill in the current sample of skilled readers or are reflecting some skill above and beyond those measured by offline reading measurements. Another possibility is that the stimuli in the current experiment was not difficult enough to elicit variance in language comprehension skills, and thus the eye movements used to process the sentences did not elicit much variance in language comprehension skills. Further research with a variety of difficult texts is needed for a more comprehensive understanding of these results.

Finally, better reading comprehension scores were associated with faster gaze durations for low-frequency long words. Indicating that early lexical access especially for low-frequency long words may benefit from better reading comprehension. Processing strategies for low-frequency words may especially be a good indicator of good reading comprehension skills since these words are often more slowly processed with increased difficulties (e.g., Ashby et al., 2005; Hawelka et al., 2010).

Taken together, these findings indicate that the component skills in the SVR may influence eye movement patterns in skilled adult readers, however, the relative influence of the component skills to eye movement patterns seems to be different from the influence the component skills have on reading comprehension. This may raise doubts about the application of the SVR to skilled adults of English and its ability to explain reading comprehension in different types of texts (i.e., simple sentences). However, it is difficult to draw these conclusions without further research comparing the component skills of the SVR to eye movement patterns while participants read different kinds of texts (i.e., newspapers, academic texts, etc.).

These results also raise the possibility that developed decoding skills and reading comprehension skills may continue to directly influence early eye movement measures even for simple sentences, whereas developed language comprehension skills and vocabulary do not. In inconsistent languages, such as English, decoding strategies tend to be less reliable than using strategies involving language comprehension abilities, (Kessler, 2003; Kessler & Treiman, 2001; Ellis & Hooper, 2001; Ziegler & Goswami, 2005), thus strong decoding skills paired with good reading comprehension may support the most efficient reading strategies for English readers. Barnes and Kim (2016) found that gaze durations accounted for unique variance in reading comprehension above and beyond decoding and language comprehension in children and low skilled adult readers. Barnes and her colleagues concluded that since the measure of gaze durations also include first fixation durations and refixations, it can be considered a measure of early word identification and lexical activation in reading. Therefore, gaze durations in particular may reflect some degree of decoding skills, but during a task of word reading (i.e., reading comprehension tasks) this measure may also reflect other skills associated with reading comprehension that were not measured in the current experiment such as automatised naming. This makes sense within the contexts of both the PGST (Ziegler & Goswami, 2005) and the ODH (Katz & Frost, 1992). Thus, when reading in an inconsistent language, good phonological decoding skills may be the distinguishing feature of the best readers in a skilled sample. Indeed, similar research using sentences as stimuli has shown that phonological chunking ability (i.e., the ability to recall phonemes from nonwords) varies among individuals and is a good predictor of sentence processing, especially complex sentences, or sentences with high phonologically overlapping words (McCauley & Christiansen, 2015; McCauley, Isbilen & Christiansen 2017).

2.3.11.3 Limitations and Further Research

One major strength of this experiment is that it examined the time-course of length and frequency effects during reading and compared both online and offline measures of reading. Results indicate however, that the eye movement measures observed in the current sample may have reflected abilities that were not measured in offline tasks, and thus these abilities are unknown. Future research would benefit from including a battery of offline tasks to measure a wider variety of reading abilities and not just the ones included in the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990). Further, since language comprehension skills did not significantly correlate with many eye movement measures, it is also possible that none of the eye movements measures in the current experiment reflect language comprehension in this sample of skilled readers. This could result due to the readers only being exposed to simple sentences, and perhaps these sentences were too easy. Future research should include a variety of easy and complex sentences to explore this possibility.

Additionally, measures of reading comprehension, may be difficult to interpret based on the nature of the way reading comprehension was measured in the current experiment. In the *Experiment 1*, reading comprehension was measured using a cloze task where participants were instructed to provide missing words from texts of increasing difficulty. A cloze task is different from the one participant completed in the current eye-tracking experiment where they read short simple sentences for meaning and answered a subsequent comprehension question. Thus, the reading results in the cloze task may be difficult to compare to the results from the eye-tracking. Future research would benefit from using several measures of reading comprehension and compare each of them with eye movement measures.

2.3.11.4 Conclusion

The present experiment aimed to explore reading strategies as measured by eye movements in skilled monolingual English native readers while they read whole sentences for meaning. Further the experiment compared eye movement measures of reading with the measured reading abilities of the components described in the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990). Frequency effects were found for both early and late eye movement measures of reading, while length effects were found for late eye movement measures of reading. Thus, there was a differential time-course of word-level effects where word-frequency affected both early and late lexical access and word-length affected later lexical access.

Language comprehension did not significantly correlate with many eye movement measures in the current sample, however decoding skills, vocabulary skills, and reading comprehension did correlate with many of the early measures of eye movements. These results indicate that an effective reading strategy for this sample included processes that were related to decoding, yet that also reflect higher order processing of sentences.

Further research is needed to determine whether similar patterns will be observed in readers with DD and bilingual readers, both of which are samples of less skilled readers.

Chapter 3: Dyslexic Reading in an Inconsistent Orthography: A Behavioural Experiment and an Eye Movement Experiment

3.1 Chapter 3 Overview

Chapter-2 investigated the SVR model (Gough & Tunmer, 1986; Hoover & Gough, 1990) in a sample of skilled native English readers and explored the relationship of the SVR component variables and eye movement patterns. As previously discussed, DD is a reading disability that affects approximately 10-12% of the English-speaking population, manifesting in beginning readers, but persisting into adulthood (Snowling, 2000). It also appears that readers of inconsistent orthographies such as English, may be disproportionately affected compared to readers of consistent orthographies (e.g., 3%-4% in Italian (Barbiero et al., 2012) 3.2 to 5.9% in Spanish (Jimenez et al., 2009). Thus, instances of DD may be related to phonological processing deficits perpetuated by inconsistent orthographies.

This Chapter again consists of two experiments; (1) a behavioural experiment where participants' reading skills such as language comprehension, vocabulary knowledge, decoding skills and reading comprehension were measured using that of offline reading assessments from the Woodcock-Munoz Language Survey III (WMLS III; Woodcock, Alcarado, & Ruef, 2017), and (2) An eye-tracking experiment where participants eye movements were tracked while they read sentences for meaning.

The current Chapter considers relevant evidence investigating phonological processing deficits in instances of DD and presents an argument for Phonological Deficit Hypothesis as a causal theory of DD. Following this, evidence from studies that have used the SVR model to demonstrate that phonological deficits, and specifically deficits in phonological decoding result in DD, will be discussed. The first experiment will test the SVR model in a sample of native English readers that have been diagnosed with dyslexia and the second experiment investigated eye movement patterns. Results from each of these studies were also compared to the results from the sample of skilled readers measured in *Experiment 1* and *2* from Chapter-2. The results from this Chapter will also be compared to bilingual readers in subsequent Chapters to explore the extent of the role of orthographic consistency in reading.

3.2 Experiment 3: The Simple View of Reading in Developmental Dyslexia

3.2.1 Theories and Subtypes of Developmental Dyslexia: A Cross-Linguistic Perspective

Although DD has been extensively investigated, researchers have not yet conclusively agreed on the root cause or a subsequent universal definition of dyslexia. The reason for this is partially because the nature of DD appears to be multifaceted and not all readers are homogeneously affected. At a theoretical level, research on dyslexia has surfaced several potential root causes of DD which may manifest in isolation or in conjunction; including deficits in auditory processing (e.g., Tallal, 1980; Share, Jorm, MacLean, & Matthews, 2002), visual attention skills (e.g., Valdois, Bosse & Tainturier, 2004), or phonological processing deficits (Ramus et al., 2003). However, two potential causes have received the most attention and support across the literature and are most relevant to this thesis and will thus be discussed in the current Chapter; (1) a phonological deficit (Ramus et al., 2003) and (2) a visual deficit largely stemming from either a magnocellular abnormality (e.g., Stein et al., 2001; 2003) or a Visual Attention Span deficit (Valdois et al., 2004). The current Chapter will offer an overview of these hypotheses and subtypes of dyslexia will be considered with the argument that phonological deficits are a common underlying factor in DD. Following this will be a discussion of how the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990) can uniquely characterize phonological deficits in dyslexic reading.

3.2.1.1 Phonological Deficit Hypothesis

The Phonological Deficit Hypothesis (Bradley and Bryant, 1978; Brady and Shankweiler, 1991; Snowling, 1981; Vellutino, 1979) is perhaps the most well-researched hypothesis concerning the basis of DD. This hypothesis predicts that DD stems from deficits in various phonological cognitive components (e.g., phonological short-term memory, phonological awareness, and phonological fluency) which affects the skills needed to efficiently decode words. The phonological deficit hypothesis is considered a single deficit model because it posits that a deficit in phonological ability is a necessary, and sufficient cause of dyslexia. The hypothesis posits that there is some impairment in acquiring the phonological abilities to efficiently learn the alphabetic principle which hinders learning the letter-to-sound-mapping (GPCs), thus impairing reading acquisition and reading fluency. This deficit is assumed to affect either the quality of representation of phonological information or in the efficiency of accessing phonological information.

The phonological deficit hypothesis has maintained support based on a substantial amount of behavioural findings that demonstrate a marked difference in phonological abilities between readers with dyslexia and typically developing readers (e.g., Boada & Pennington, 2006; Lieberman, Meskill, Chatillon, & Schupack 1985; Muter, Hulme, Snowling, & Taylor, 1998; Ramus, 2003; Wydell & Butterworth, 1999), as well as neuroimaging studies which demonstrate patterns of deficits in the left-hemisphere associated with language during reading for dyslexic readers compared to controls (e.g., Bonte & Blomert, 2004; Hoeft et al., 2007; Simos et al., 2007; Shaywitz et al., 2002; 2004). Further, research has demonstrated that among predictors of DD, a core phonological processing deficit remains a consistent finding in studies on dyslexia (e.g., Hatcher et al., 1994; Shankweiler et al.,1992). For example, Rack, Snowling, and Olson (1992) presented a review of several studies that together, involved over 400 dyslexic children and reading-level matched typically developing children. The conclusion from the reviewed data across all these studies was that there was a marked difference between dyslexic readers and reading-level matched controls on measures of phonological reading skill, particularly nonword reading. As previously discussed, phonological deficits are consistently associated with difficulties in fluent and accurate word reading which persist into adulthood (e.g., Hatcher, Snowling & Griffiths, 2002; Hulme et al., 2012; Melby-Lervåg, Lyster & Hulme, 2012; Share & Stanovich, 1995; Snowling, 1995; Snowling, Nation, Moxham, Gallagher & Frith, 1997; Wydell & Kondo, 2003). Further, many skills associated with phonological processing such as phonological awareness, phonological working memory, and lexical access are also impaired in readers with dyslexia (Vellutino et al., 2004).

DD has been simulated in several computational models of reading, e.g., DRC (Coltheart et al., 2001), PDP: (Harm & Seidenberg, 1999; Seidenberg & McClelland, 1989) or Triangle models (Plaut et al., 1996). Although the DRC was initially developed to account for skilled reading and acquired dyslexia (Coltheart et al., 2001) phonological deficits are thought to affect processing via both the lexical and the sub-lexical route. This model argues that a problem with the sub-lexical route is characterized as phonological dyslexia while impairment in the lexical route is characterized as surface dyslexia. This distinction stems from evidence of a discrepancy between children's performance in reading words that have an irregular grapheme-phoneme correspondence which would require the lexical route to process, and performance on reading nonwords, which require the sub-lexical route. For example, Castles and Coltheart (1993) compared the performance of children with dyslexia with age-matched controls on regular, irregular, and nonword reading. The typically developing children's performance for all words were highly correlated while the dyslexic group showed a dissociation between these measures. Specifically, forty-five out of the fifty-three dyslexic children showed a significant dissociation between exception word and nonword performance. Twenty-nine of these children showed deficits in nonword reading compared to irregular word reading (phonological dyslexia), while sixteen showed the opposite pattern (surface dyslexia). This study highlighted a possible dissociation between irregular word reading and nonword reading and the higher prevalence of problems with nonword reading compared to irregular word reading.

However, based on a comparison of children with a surface dyslexia profile and reading-level matched controls, Manis et al. (1996) argued that surface dyslexia may just reflect a developmental delay rather than an impairment to the lexical route. In this study, the children with surface dyslexia demonstrated similar reading performance to the reading-level matched controls (as opposed to age-matched). However, it is still important to emphasize that both children with a surface dyslexia profile still perform worse than typically developing children on word and nonword reading.

Alternatively, connectionist Parallel Distributed Processing (PDP) models or triangle family models (Plaut et al.,1996; Seidenberg & McClelland, 1989) assume that the system for reading irregular words and nonwords is the same. Connectionist models account for the impairment of both irregular and nonword reading impairments by assuming this occurs as a result of an impaired phonological component in the network resulting in impaired phonological representations of all letter strings, but for nonwords more than real words (Harm & Seidenberg, 1999, Harm & Seidenberg, 2001). Nonwords are more adversely affected because nonword pronunciation is based on generalizations of patterns from experience with pronouncing real words in the first instance. Irregular words may still be read relatively successfully given experience even with mild phonological impairment, however a severe phonological impairment may still impair irregular word reading.

Although both models may have limitations as previously discussed in Chapter-1, it is important to note that both connectionist models and the DRC recognize a role of phonology. The goal of the current Chapter was not to directly test the different theoretical conceptions of these models; however, these models are useful to provide a context in which behavioural data may be conceptualised.

The goal of the current Chapter was to investigate the manifestation of the performance of phonological processing in adult readers of an inconsistent orthography with and without dyslexia. Indeed, many independent sources of evidence converge on the foundational role of phonology in both typically developing reading, and poor reading, and the Rose (2009) definition discussed in Chapter-1, that was adopted for the purposes of this thesis, clearly highlights the difficulty with fluent and accurate word reading as a central marker of dyslexia. However, there is contention as to whether a phonological deficit itself is a cause of dyslexia, or whether phonological deficits manifest externally as a consequence of some other underlying, but related deficit (e.g., a visual deficit linking to the magnocellular abnormality in the LGN: Hansen, Stein, Orde, Winter and Talcott, 2001; Stein, 2001; 2003). A critical discussion of these hypotheses will be offered for the purposes of the current thesis.

3.2.1.2 Visual Deficit Hypotheses

In contrast to the Phonological Deficit Hypothesis, some researchers have argued that DD may stem from impaired visual processing, which in turn affects word reading fluency and phonological abilities (Livingstone et al., 1991; Lovegrove et al., 1980; Stein and Walsh, 1997). It is important to note that the visual theory does not exclude a phonological deficit, but emphasizes a visual impairment component in reading problems, at least in some dyslexic individuals.

There are two supported accounts for dyslexia caused by visual impairments: (1) the Magnocellular Deficit Hypothesis (Stein, 2001), which suggests that reading difficulties in DD derive from reduced sensitivity of the magnocellular visual system in the LGN and (2) the Visual Attention Span Deficit hypothesis which posits that reading impairments are caused by an impairments in the visual attention span (Valdois et al., 2004).

3.2.1.3 The Magnocellular Deficit Hypothesis

The magno-cells comprise 10% of the ganglion cells whose axons provide the signals that pass from the eye to the rest of the brain (Enroth-Kugel and Robson, 1969; Shapley and Perry, 1986), and called as such because they are noticeably larger than the reminder parvo-cells. Magno-cells project onto the visual area in the occipital cortex via the magnocellular layer in the dorsal lateral geniculate nucleus (LGN). The magnocellular pathway allows the rapid perception of moving stimuli (i.e., prevents blur from eye movements) while keeping the eye focused on a target, and is sensitive to changes in brightness and low-spatial frequency, but is relatively insensitive to colour and fine detail. The magnocellular system is distinct from the parvocellular system and deficits in each system can be distinguished one from the other (e.g., Sperling, Lu, Manis & Seidenberg, 2003). According to the Magnocellular Deficit Hypothesis, instances of dyslexia emerge specifically from underdevelopment or a deficit in the magnocellular layers. Thus, their motion sensitivity is reduced, impairing their monitoring of visual movements leading to visual confusion, unsteady binocular fixation, and poor visual localization (Stein, 2001). Each of these elements are important to successful reading performance.

Supporting evidence for the Magnocellular Deficit Hypothesis comes from studies showing abnormalities in the magnocellular layers (e.g., Livingstone et al., 1991), and studies that find a decrease in sensitivity in the magnocellular range in dyslexics (i.e., low spatial frequencies and high temporal frequencies) (e.g., Lovegrove et al., 1980). However, several studies have suggested that a deficit in the visual magnocellular pathway occurred only in a subset of a sample with DD (e.g., Ramus, 2003; Stein, Talcott, & Walsh, 2000). Further, some studies have failed to find evidence for a deficit in the core magnocellular region from a neural level (e.g., Goswami 2015; Hutzler et al., 2006). There is also inconsistent evidence that interventions for a magnocellular deficit improve reading. For example, the use of colour overlays for children with reading difficulties are often considered to have a placebo effect rather than a real effect on reading (e.g., Denton & Meindl, 2015; Stein 2012; Tholen et al., 2011).

3.2.1.4 The Visual Attention Span Deficit

The visual attention span (VA Span) deficit (Bosse et al., 2007; Valdois et al., 2004), posits that another cause of dyslexia stems from limited visual attention resources which prevents normal processing of visual stimuli (i.e., printed words). The VA span is defined as the amount of distinct visual components that can be processed in parallel in a multi-element array. The VA Span hypothesis builds on the Multi-Trace Memory model of reading (MTM Model; Ans, Carbonnel, & Valdois, 1998) which posits the existence of a visual attention window through which visual stimuli is processed and was the first model to emphasize the importance of visual attention in reading. The MTM model postulated that reading relies on two different reading procedures, a global (parallel) procedure and an analytic (serial) procedure each with a different attentional window size and thus differ in the VA and phonological processes they involve.

Familiar words are processed via the global procedure, which allows the window to open around the entire letter-string and the entire phonological output is processed in one step. The window in the analytic procedure narrows for unfamiliar and nonwords such that attention can be focused on smaller bits of visual stimuli to serially match orthographic units to their corresponding phonological units in a sequence which has to be maintained in the short-term memory. It is important to note that these procedures are not a-priori dedicated to processing certain types of words but rather, the global procedure processes the letter-string unless it fails and subsequently the analytic procedure processes the letter-string.

Following this, the VA Span hypothesis suggests that a VA span reduction (i.e., a reduction of the number of visual stimuli that can be processed simultaneously) would hinder normal decoding of letter-strings, and that this would pose a particular consequence for reading irregular words that cannot be decoded serially (Bosse et al., 2007). Indeed, Ans et al.

(1998) tested the MTM model and found that a moderate reduction of the VA window disrupted processing in the global procedure, which simulated surface dyslexia with some selective disruption of irregular word reading. When the VA window was further reduced, performance was disrupted even further with the number of errors for processing both regular and irregular words increasing but was particularly impaired in processing irregular words. Thus, the MTM postulates a causal relationship between the VA span disorder and reading difficulties.

Though some researchers find supporting evidence for visual deficits in participants with dyslexia either due to a deficit in the magnocellular pathway or a visual attention span deficit, results seem to be inconclusive with some other researchers reporting no significant visual deficits (e.g., Amitay, Ben-Yehudah, Banai & Ahissar, 2002; Chiappe, Stringer, Siegel & Stanovich, 2002; Olson & Datta, 2002; Ramus, et. Al., 2003). For example, Goodbourn et al. (2012) found a low correlation between dyslexia and magnocellular tasks. In another study, the VAS global report task in English did not demonstrate visual attention span deficits (Wydell & Fern-Pollak, 2013). Ramus and colleagues (2003) attempted to directly assess three theories of DD: (i) the phonological theory, (ii) the magnocellular (auditory and visual) theory and (iii) the cerebellar theory[2]. Their sample included 16 university students with dyslexia and 16 control participants. Participants were asked to complete a battery of psychometric, phonological, auditory, visual, and cerebellar tasks. The results revealed that all 16 of the dyslexic participants demonstrated a phonological deficit compared to controls, a subset of 10 suffered from an auditory deficit, four from a motor deficit, and two from a

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[2] The cerebellar deficit hypothesis (Nicolson & Fawcett, 1990; 2005) claims that dyslexia stems from a cerebellar dysfunction, which leads to impairments in motor and visual domains and also impairs automization of abilities such as processing speed, rapid naming and reading).

visual magnocellular deficit. These results suggest that a phonological deficit can impair reading on its own in the absence of any other impairments. Further, these results demonstrate that a phonological deficit may still exist among readers with dyslexia who also show impairments in other sensory or motor skills. These findings support the notion that there may be smaller subgroups of children with dyslexia who also have deficits in motor or auditory processing, but overall support the Phonological Deficit Hypothesis as being a sufficient and core underlying deficit of dyslexia.

Overall, it appears that perhaps only a subset of readers with DD suffers from some visual or auditory impairment, while some deficit in phonological processing is consistent across all readers with dyslexia. DD is being increasingly acknowledged across the literature as being a multi-faced disorder that may manifest from several contributing factors (e.g., Hulme and Snowling, 2009; Menghini et al., 2010). These factors generally range from verbal and visual processing speed (Neuhaus, Foorman, Francis & Carlson, 2001; Wimmer & Mayringer, 2001; Windfuhr & Snowling, 2001), phonological awareness (Hulme, Bowyer-Crane, Carroll, Duff & Snowling, 2012; Melby-Lervåg, Lyster & Hulme, 2012; Share & Stanovich, 1995; Snowling, 1995; Snowling, Nation, Moxham, Gallagher & Frith, 1997), and visual attention (Peyrin, Démonet, N'Guyen- Morel, Le Bas, & Valdois, 2011). It is common among practitioners to assess each of these components to construct an accurate profile of a suspected individual with DD. However, increasing cross-linguistic findings are emerging those readers of English (an inconsistent orthography) appear to be disproportionately affected by dyslexia than readers of consistent orthographies such as Italian or Spanish (e.g., Barbiero et al., 2012; Jimenez et al., 2009; Snowling, 2000; Shaywitz et al., 1999; Wydell & Butterworth, 1999; Uno, Wydell, Haruhara, Kaneko & Shinya, 2009). Visual theories of DD such as the Magnocellular Deficit Hypothesis (Stein, 2001) and the Visual Attention Span Deficit (Valdois et al., 2004) cannot account for these findings, while the Phonological Deficit Hypothesis can. A review of findings of the manifestation of DD in other orthographies will be offered with a consideration of theoretical models that may account for the differences in DD across orthographies.

3.2.1.5 Orthographic Depth and Reading Impairments Across Orthographies

Perhaps some of the most compelling evidence for both the Phonological Deficit Hypothesis (Ramus et al.,, 2003; Vellutino et al., 2004) and the ODH (Katz & Frost, 1992) is that there appears to be a dissociative prevalence of dyslexia between different orthographies. For example, in English-speaking countries, the prevalence of dyslexia is reported to be around 10%-12% (Snowling, 2000; Shaywitz et al., 1999). However, the prevalence of dyslexia in languages with spelling systems that are more regular (i.e., consistent grapheme-phoneme conversion) appears to be much lower. For example, in Italian, the reported prevalence of dyslexia is around 3%-4% (Barbiero et al., 2012) and in Spanish, it ranges from 3.2 to 5.9% in elementary school students (Jimenez et al., 2009). In Japanese, the prevalence of reading difficulties differs across different scripts (Uno, Wydell, Haruhara, Kaneko & Shinya, 2009). It is reported to be 0.2% in transparent syllabic Hiragana, 1.4% In transparent syllabic Katakana and 6.9% in opaque logographic Kanji. Models of visual impairments cannot account for these differential prevalence rates in DD across different orthographies, because a deficit in the VA span or the magno-cells would not be affected by orthography and should remain affect all readers at a consistent rate. Phonology and phonological skills on the other hand, may be acquired and applied to reading differently depending on the orthography being read.

Reading in an inconsistent orthography encourages a whole-word approach to meet the demands of the inconsistent GPCs (Frost et al., 1987; Marinelli et al., 2016; Ziegler & Goswami, 2005) because serial decoding often leads to errors in pronunciation (Wimmer, 1993). While consistent orthographies may be read successfully using a serial decoding strategy due to the ease of processing the consistent GPC patterns (Frost et al., 1987; Ziegler and Goswami, 2005). Dyslexia in consistent languages is often characterized as slow, but reasonably accurate reading (Coltheart and Leahy, 1996; Martens and de Jong, 2006; Suárez-Coalla and Cuetos, 2015; Wimmer, 1993; Zoccolotti et al., 1999; Ziegler and Goswami, 2005). Thus, phonological deficits may be better at characterizing this differential prevalence in different orthographies.

The HGT, as introduced in Chapter 1, argues that phonological dyslexia would be rare in two conditions: (1) in transparent orthographies where the GPCs are one-to-one regardless of the level of translation of orthographic units to phonological units (i.e., at the phoneme, syllable level or whole-character level and (2) even in opaque orthographies, if the smallest graphemic unit representing sound is equal to a whole character or a whole word (i.e., coarse grain), as opposed to a syllable or phoneme (i.e., fine grain), it will not produce a high prevalence of phonological dyslexia. Any orthography can be placed in this transparency-granularity dimension as illustrated in Figure 16 and a language that falls within the shaded area would yield very low instances of phonological dyslexia (Wydell & Butterworth 1999; Wydell & Kondo, 2003; Ijuin & Wydell, 2018).

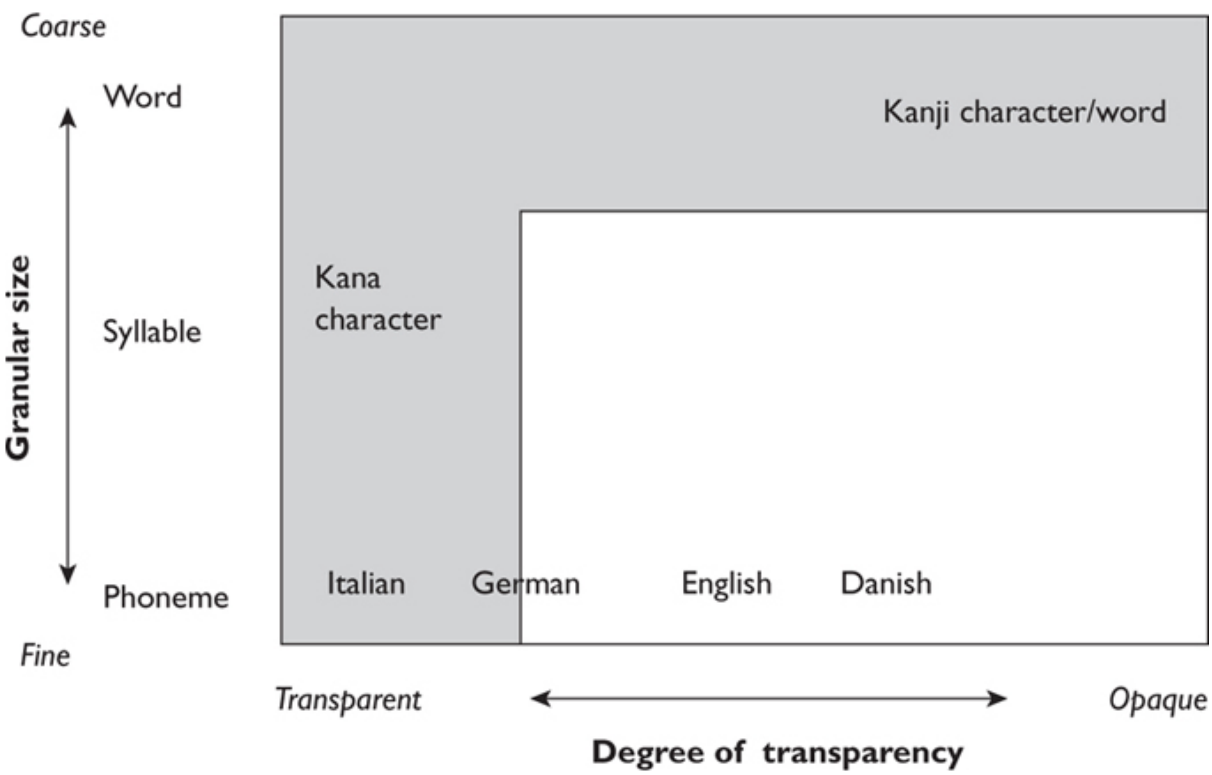

Figure 16. Hypothesis of Granularity and Transparency (adapted from Wydell & Butterworth, 1999).

Note that the Japanese writing system consists of two different scripts which vary in terms of their orthographic structure: (1) there is the logographic, morphographic Kanji, and (2) two forms of syllabic Kana, Hiragana and Katakana (Wydell, Patterson, & Humphreys, 1993). Japanese Kana is a transparent script, and Japanese Kanji is opaque, but composed of coarse grains while English is an opaque language with fine grain sizes. Thus, instances of dyslexia particularly phonological dyslexia would be high in English, but low in Japanese kana or kanji (Wydell & Butterworth 1999; Wydell & Kondo, 2003).

Later, Ijuin and Wydell (2018), modelled reading in Japanese syllabic kana and morphographic kanji based on Harm and Seidenberg's (1999) connectionist model for reading in English to simulate the granularity dimension of the HGT. Specifically, the model examined naming latency differences between Japanese kanji and kana. According to the HGT, reading latency of kanji (with larger granularity) should be shorter with higher accuracies than that of kana (with smaller granularity). The simulation was successful in supporting these assumptions, but also indicated that there were other factors that affected performance in the model such as the mora frequency.

Taken together, based on the HGT and the above empirical evidence, it is expected that reading in an inconsistent language such as English would yield a higher rate of disruption to phonological skills such as decoding, while in consistent languages there may be no such disruption.

To summarize, DD is a multifaceted and complex developmental disorder, with various contributing factors that must be recognized, however, it appears as though phonology plays a central role either as the expression of an underlying cause, or as a cause itself of DD. The current thesis does not discount the research that has demonstrated visual or auditory deficits in subtypes of DD, however, converging research discussed above demonstrates a significant and consistent role of a phonological deficit in DD. For this reason, the nature of phonological processing in readers with dyslexia still warrants extensive investigation. Further, the role of orthographic depth as a contributing factor to instances of dyslexia should also be investigated further. A good way of investigating phonological processing across orthographies is through comparisons of readers of different orthographies. This is an important investigation especially because of the growing number of bilingual children in English speaking countries. Current definitions of DD and assessment tools used by practitioners are not yet equipped to account for individual needs of bilinguals. This is particularly salient with bilingual readers who may be classified as poor readers in English, but not in their native language. A critical question that arises is whether poor bilingual readers may differ from poor monolingual readers who meet the criteria for dyslexia. This question will be further investigated in Chapter-5.

It is important to note here that the current thesis investigates reading processes in readers of alphabetic languages only. Although the HGT offers an account of reading across all types of orthographies, we note that there are some specific differences between alphabetic and non-alphabetic scrips (e.g., Chinese). Chinese is not a phoneme-based language and early phonology is not activated (Wei et al., 2014): at the orthographic level, there is no orthographic overlap between Chinese and English, and any influence of orthographic similarity on cross-lingual phonological priming effects are ruled out. Alphabetic writing systems such as English have sublexical units (i.e., letters/graphemes). It is this characteristic that allows for prelexical phonological assembly and the use of grapheme-to-phoneme conversion rules in English. In Chinese, the graphemic unit corresponds to a whole syllable; thus, phonological assembly is not possible (Perfetti, Liu, & Tan, 2005).

3.2.2 The Simple View of Reading and Developmental Dyslexia

Although a phonological deficit may be a common factor across readers with dyslexia, it has not yet been unilaterally supported as a single cause of DD. Snowling et al. (2003) have argued that a deficit in oral language may be an additional causal factor in dyslexia. They used a longitudinal design to track the development of children (aged 3-8) at familial risk for dyslexia, compared to controls. Each child was assessed at three different points; once at age 3, age 6, and age 8 on a battery of cognitive tests. Consistent with the prediction that there is a higher risk of dyslexia for children who have families with dyslexia, 66% of children in the high-risk group were classified as reading impaired compared to only 13% in the control group (low-risk) based on significantly poorer performance on tests of reading comprehension at age 8. In addition to poorer reading comprehension scores, the children who were classified as reading impaired showed deficits on tests of phonological awareness (phoneme deletion and rhyme oddity) and phonological processing (nonword repetition), but also showed deficits in oral language skills including listening comprehension and vocabulary at age 8. Retrospective analyses revealed that at age 3, all the children in the high-risk group performed worse than controls on tests of letter knowledge and rhyming, but high-risk children who later met the criteria for a reading impairment performed significantly worse than high-risk children later classified as unimpaired (who in turn performed at the same level as controls) on tests of vocabulary development and expressive language. Importantly, compared to the low-risk control group, the children in the high-risk group who did not subsequently meet the criteria for a reading impairment still performed as poorly as the high-risk impaired children on some tests of phonological awareness (nonword reading and phonetic spelling). However, at age 6, the unimpaired high-risk children performed as well as controls, and significantly better than high-risk impaired children on measures of oral language (oral vocabulary and listening tasks). Snowling and her colleagues (2003) suggested that the high-risk unimpaired children were able to compensate for poor phonological ability by relying more heavily on oral language skills.

These results were interpreted within the triangle model of reading (Harm & Seidenberg, 1999, 2004; Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McClelland, 1989) to suggest that problems in the semantic component could increase the chance of word reading problems in children who have a phonological deficit, but good oral language skills may serve as a compensatory path for children with a phonological deficit resulting in unimpaired word reading skills. However, it is important to point out that the high-risk unimpaired group also began to perform better than high-risk impaired children on some measures of phonological abilities at age 6 (i.e., spelling and word reading) and began to perform at a similar level to controls on other measures of phonological ability (i.e., a rhyming task and letter knowledge). By age 8, they outperformed the high-risk impaired group on all phonological tasks. This invites the question of whether these children ever had a phonological deficit in the first place, or whether their performance may have indicated a developmental delay. This may be the case as cross-sectional and longitudinal investigations of phonological abilities of dyslexics have demonstrated that dyslexics may not acquire an adequate level of phonological awareness skills even in adulthood (e.g., Bruck, 1992; Shaywitz et al., 1999).

In a more recent longitudinal study, Catts et al. (2017) followed the reading development of phonological awareness, oral language, and rapid automatized naming of 262 children from the beginning of kindergarten to the end of Grade-2. Using structural equation modelling, the authors demonstrated that children who had a deficit phonological awareness in kindergarten were five times more likely to meet criteria for dyslexia in Grade-2 than children without a deficit. Further, if the children who had deficits in phonological awareness also had deficits with oral language and rapid naming, their risk for dyslexia increased substantially.

Taken together, these studies demonstrated the need for inclusion of both phonological ability and oral language skills (even including vocabulary skills) when considering reading impairments. Readers with poor phonological abilities, but good oral language abilities may develop compensatory strategies resulting in unimpaired word reading. Oral language and phonological decoding skills can both be assessed and dichotomized within the SVR Model (Gough & Tunmer, 1986, Hoover & Gough, 1990). For this reason, the SVR will be used as a way to measure and evaluate a variety of reading skills in a sample of readers diagnosed with DD in the current Chapter.

The SVR (Gough & Tunmer, 1986, Hoover & Gough, 1990) was referenced in the definition of dyslexia offered by Rose (2009) as a model for conceptualizing different patterns of literacy performance in typically developing children and children with reading impairments. The SVR posits that reading comprehension is the product of decoding skills and language comprehension skills and predicts that if either decoding or language comprehension is impaired, reading comprehension will also be impaired. Specifically, readers may be classified as either (1) an individual with good ability in both language comprehension and decoding skills (a skilled reader), (2) an individual with impaired decoding only, (3) an individual with impaired language comprehension only, or (4) an individual with both impaired decoding and language comprehension.

According to the Rose (2009) definition of dyslexia, readers who fall into the two left quadrants (see Figure 3 (p.45) in Chapter-1) who are experiencing some level of difficulty with word recognition and decoding could likely be characterized as dyslexic. Thus, there may be distinction between children who struggle with accurate word identification, and those who do not regardless of language comprehension skills. This distinction may be important because children with dyslexia may not necessarily struggle to comprehend a text that is read aloud to them but do struggle to accurately decode words when they read themselves (Frith & Snowling, 1983). On the other hand, students who show no phonological impairment, but fail to construct meaning from a text, are considered to have specific language impairment (SLI). These children commonly exhibit deficits in semantics, syntax, and discourse (Leonard, 1998; Tager-Flusberg & Cooper, 1999).

This distinction has been supported by studies that investigated the behavioural profiles of students with SLI and students with dyslexia. For example, Catts, Adlof, and Weismer (2006) tested the SVR model on three groups of Grade-8 children; those with normal decoding ability, but with poor reading comprehension skills, those with poor decoding skills, but with normal reading comprehension skills, and students who had both normal reading comprehension and decoding skills. The authors found that the SVR formula (RC = D x LC) could be modified to (LC = D x RC) and demonstrated that the SVR could accurately predict that strong decoding skills paired with poor reading comprehension will result in poor language comprehension. Further, moving in the other direction, poor decoding skills paired with normal reading comprehension skills may still yield normal abilities in language comprehension. Group comparisons demonstrated that in Grade-8, readers with poor language comprehension ability performed worse than poor decoders and age-matched controls on measures of receptive vocabulary and grammatical skills. Poor decoders on the other hand performed significantly worse than both controls and readers with poor language comprehension skills on measures of phonological ability. Retrospective analyses from the longitudinal data (Tomblin et al., 1997) revealed similar patterns for these same children at Grade-4 and Grade-2.

It should be noted however, that the Rose (2009) definition emphasizes that the primary difficulties of children with dyslexia include phonological awareness, verbal memory and verbal processing speed, and that dyslexia is best thought of as a continuum and not a distinct category. The SVR model also acknowledges that reading skill falls along a continuum and that each of the four quadrants are not distinct categories, but dimensions that readers may fall into based on their skills on the dimensions. Therefore, there may be some overlap between deficits with language comprehension and deficits with phonological decoding ability. In a comprehensive review of evidence from behavioural, etiological, cognitive, and neurobiological factors contributing to SLI and dyslexia Bishop and Snowling (2004) argue that although there may be some behavioural overlap between SLI and dyslexia, it is best to maintain a distinction between deficits with accurate word identification and difficulties with comprehension of spoken language. This conclusion was largely based on the notion that although these disorders may appear similar at the behavioural level, evidence suggests they may have different causal origins. For example, family and twin studies revealed that each of these reading impairments have genetic components with differential rates of heritability (e.g., Bishop, 2001; Flax et al., 2003). For a more recent review of this evidence, see Adolf (2020).

Indeed, researchers who have used the SVR model to characterise impaired reading often find a low correlation between decoding abilities and language comprehension abilities. The SVR has proven useful at distinguishing these two behavioural profiles of readers with dyslexia and readers with SLI. The component variables of decoding and language comprehension each comprise these skills, which are independent as predicted by the SVR. Specifically, findings from testing the SVR find that reading comprehension will be impaired for children who demonstrate impairments in fluent and accurate word identification despite having adequate language comprehension skills (Gough & Tunmer, 1986; Perfetti, 1985; Snowling, 2000; Stanovich, 1991; Vellutino, 1979: Vellutino, Scanlon, & Tanzman, 1994).

Similarly, these same studies demonstrate the opposite, that poor oral language skills with relatively intact decoding skills may still predict poor reading comprehension. Readers with poor word reading skills demonstrate difficulties in areas such as phonological awareness and phonological memory (Catts & Kamhi, 2005; Lyon, Shaywitz, & Shaywitz, 2003), whereas readers with poor language comprehension skills perform as well as typically developing readers on these skills (e.g., Cain, Oakhill, & Bryant, 2000; Nation, Adams, Bowyer-Crane, & Snowling, 1999; Nation & Snowling, 1998). On the other hand, readers with poor language comprehension abilities perform worse on tasks that involve receptive vocabulary and semantic or grammatical processing (e.g., Nation et al., 2004; Nation & Snowling, 1998a, 1998b,1999) and comprehension of spoken discourse (e.g., Cain et al., 2001; Nation & Snowling, 1997).

Taken together, the SVR can help to explain the some of the behavioural bases of heterogeneity in reading impairments and can differentiate readers with dyslexia as having particular deficits in phonological decoding, which is associated with a larger behavioural profile that includes deficits with a wider range of phonological abilities such as phonological memory and verbal ability (Hatcher, Snowling & Griffiths, 2002; Vellutino et al., 2004) from readers with SLI who have a distinct profile associated with semantic abilities (Cain et al., 2001; Nation & Snowling, 1997). These findings may also support the Phonological Deficit Hypothesis which predicts there is a link between word-reading deficits and problems in phonological processing leading to reading impairments (Stanovich, 2000). For these reasons, the current experiment will use the SVR model (Gough & Tunmer, 1986; Hoover & Gough, 1990) to investigate individual variability in reading comprehension in a sample of adult readers diagnosed with dyslexia.

3.2.2.1 The Product Model vs. the Additive Model of the Simple View for Dyslexic Readers

As previously discussed, (Chapter-2), Savage and Wolforth (2007) sampled a group of graduate and undergraduate university students with and without diagnosed reading disorders and found that both the additive model and the multiplicative model had adequate predictive power. However, the sample of both readers with and without dyslexia were analysed as whole, the authors did not analyse typical readers and readers with dyslexia separately. Again, it is possible that this range of skill in a sample of readers with and without reading disorders may have increased the strength of a product model, or it is equally possible that the predictive power of the multiplicative model was driven by one of the two groups.

In 2012, Pennington et al. investigated predictors of reading comprehension including phonological decoding skills, language comprehension and naming speed in a sample of children aged 11 with and without dyslexia. The sample was first analysed as a whole with both dyslexic and age-matched typically developing children. Multiple regression techniques revealed that phonological decoding skills was the best predictor of reading comprehension predicting nearly 55% of variance in reading comprehension. Language comprehension made a significant unique contribution of around 7% above and beyond phonological awareness, and naming speed accounted for an additional 3% of variance in reading comprehension. Though it was a small contribution, the multiplicative model of D x LC also contributed a unique proportion of variance (1%) above and beyond all of these factors. However, when the analyses were performed on each subgroup (dyslexic vs. typically developing), results revealed that the multiplicative model only accounted for unique variance for the typically developing readers who had good reading skills. However, the analysis for the dyslexic subgroup revealed that these factors made an additive contribution to predicting variance in dyslexic's reading which was poor. Thus, it appears as though reading skills for typically developing readers may best be characterised by the interactive multiplicative model of the SVR while reading skill for dyslexic readers may best be characterised by an additive model of the SVR. However, more specifically, these results may indicate that the multiplicative model characterises *good* reading skill, while the additive model characterises *poor* reading skill. A good way to investigate this question is to analyse these skills in a sample of adult readers with dyslexia who are enrolled in a university and may have developed adequate reading skills despite a history of dyslexia. To our knowledge, a comparison of the additive and multiplicative model has not been investigated in adult readers with a history of dyslexia. For these reasons, the current thesis measured and analysed decoding, language comprehension and reading comprehension in a sample of adult readers with dyslexia enrolled in university.

3.2.2.2 The Role of Vocabulary as an Additional Predictor of Reading Comprehension

As previously discussed (Chapter-2) and as evidenced by *Experiment 1* in the same Chapter, vocabulary knowledge has been found to account for unique variance in reading comprehension above and beyond decoding and language comprehension (Binder et al., 2017; Braze et al., 2007; Vellutino et al., 2007; Ouellette & Beers 2010; Tunmer & Chapman, 2012).

Vocabulary may be a particularly useful tool for readers with dyslexia to compensate for poor decoding skills, however there is still some debate as to whether vocabulary skills are poorer in readers with dyslexia compared to typically developing readers. Some studies have reported that vocabulary skills are significantly worse in readers with dyslexia. For example, Snowling and colleagues (1997) found that university students with dyslexia performed worse than age-matched typically developing readers on a measure of vocabulary from the Wechsler Adult Intelligence Scale-Revised (WAIS-R), where participants are asked to read words and provide definitions.

On the other hand, some studies demonstrate that children with dyslexia do not appear to perform worse than typically developing children at vocabulary tasks. These differences may stem from the way vocabulary is measured. For instance, Snowling, van Wagtendonk and Stafford (1988) used a picture naming task to assess vocabulary size in children with dyslexia and typically developing children. They found that when asked to match pictures to spoken words, children with dyslexia performed as well as typically developing children, however when asked to provide the written words, the typically developing children outperformed the children with dyslexia. These findings suggest that perhaps vocabulary is intact for readers with dyslexia compared to typically developing readers, but that differences arise when asked to spell these words. The current experiment aimed to test vocabulary knowledge in a sample of adult readers diagnosed with DD to determine the extent to which vocabulary knowledge may differ from typically developing readers and the extent to which it can characterise reading comprehension.

3.2.3 Experiment 3: The Current Experiment

The current Chapter has established that instances of DD are largely associated with a phonological deficit, and that DD may disproportionately manifest in an inconsistent orthography compared to consistent orthographies where GPCs are consistent. Further, the current Chapter has also demonstrated the separation of reading comprehension problems due to decoding and those due to language comprehension. It follows that readers of a consistent orthography may not struggle with decoding to the same extent as a reader of an inconsistent one leading to potential for a deficit. Thus, if deficits with word identification and phonological processing are distinct from deficits in comprehension, then we might expect that readers of an inconsistent orthography may be disproportionately affected by problems with word identification.

The current experiment focuses specifically on the reading abilities in adult readers who have been identified as dyslexic, who have poor word reading ability (i.e., decoding). According to the SVR and the Phonological Deficit Hypothesis, readers with dyslexia should be characterised as having poor word reading abilities, but reasonably good oral language skills compared to typically developing readers. It is important to note that the current thesis does not argue that phonological deficits are the only cause of DD, but rather that it is a common underlying factor. Further, the current thesis does not discount findings that some subtypes of readers with dyslexia may also have a visual or auditory impairment contributing to their literacy deficits. However, it is argued that the phonological deficit is one of the greatest common influencers.

The goal of the current experiment was to consider the reading components described in the predictions of the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990) and to determine the extent to which decoding and language comprehension abilities and vocabulary knowledge drive the strategies involved in dyslexic reading in an inconsistent orthography. A model such as the SVR has both educational and diagnostic implications. Due to its supported effectiveness, the SVR has been used to implement reading development strategies and to provide interventions to students struggling with reading difficulties in classrooms. The Rose Report (2009) has adapted the use of the SVR in classrooms as a framework to develop curriculum in primary schools in the U.K. (Rose, 2009; DfES, 2006).

For these reasons, reading abilities were measured in a sample of college aged native English monolingual readers with a diagnosis of DD.

Hoover and Gough (1990) suggested that decoding ability for skilled readers is best measured from word identification tasks rather than nonword reading tasks. Accordingly, the present experiment will use a word identification task to measure decoding. Similarly, Hoover and Gough (1990) also suggested language comprehension measures should encompass listening skills, vocabulary knowledge, and semantic integration. The current experiment will use a subtest from the Woodcock-Munoz Language Survey III (Woodcock, Alcarado, & Ruef, 2017) meant to measure each of these abilities (i.e., language comprehension, decoding skills, reading comprehension and vocabulary knowledge).

3.2.3.1 Hypotheses

The current experiment aimed to investigate the following hypotheses:

1. According to the substantial number of findings that readers with dyslexia demonstrate phonological impairments even persisting into adulthood, it was expected that in a sample of adult readers who had been diagnosed with dyslexia would have impaired decoding skills. Further, if decoding skills are indeed impaired, it is also expected that decoding and language comprehension will demonstrate a different pattern of contribution to reading comprehension compared to typical readers of English.

2. Previous research has demonstrated that decoding and language comprehension scores are not highly correlated in readers with dyslexia who have impaired decoding skills. Thus, it was expected that these constructs would not be highly correlated in the current sample of readers with dyslexia. However, it was expected that both constructs should be correlated with reading comprehension. Given that research has observed that decoding is of a greater influence for younger readers and that language comprehension becomes a greater influence as readers gain experience

and skill (Caravolas et al., 2019; Barnes & Kim, 2016; Goswami, 2002; Gough & Tunmer, 1986), it was also expected that the language comprehension scores should be better than decoding scores at predicting reading comprehension scores.

3. The SVR predicts that all variance in reading comprehension can be accounted for by the product of decoding and language comprehension skills. However, in *Experiment 1*, with typical adult readers, the product model was not significantly better than the linear model at accounting for variance in reading. In the current sample of adult readers with dyslexia, the same results are expected.

4. Given that many studies demonstrate that vocabulary skills are intact in readers with dyslexia, and given the findings from *Experiment 1* and other evidence that vocabulary may account for unique variance in reading comprehension above and beyond language comprehension and decoding (Binder et al., 2017; Braze et al.l, 2007; Vellutino et al., 2007; Ouellette & Beers 2010; Tunmer & Chapman, 2012), it was expected that adult readers with dyslexia would have adequate vocabulary skills and that these would contribute to unique variance in reading comprehension.

3.2.4 Methods

3.2.4.1 Ethics Statement

Both Experiment 3 and 4 were approved by The Institutional Ethical Review Board, University of Brunel London, Department of Psychology, United Kingdom (number IP -IRB/11942-LR-Aug/2018- 13812-2) (see Appendix 1). Written informed consent was obtained from each participant (see Appendix 2b), after participants read an information sheet (see Appendix 2a) about the purpose of the experiment and their right to withdraw at any point in time without giving a reason.

Reading Behaviour Between a Consistent and an Inconsistent Orthography

3.2.4.2 Participants

The sample consisted of 14 English monolingual readers with DD aged 18-29 (11 females M_{age} = 21.50, SD = 3.88), who were recruited from Brunel University London's research pool and participated for course credit. All participants had normal or corrected-to-normal vision and were native English speakers. Participants all indicated that they had received a formal diagnosis of dyslexia from either an educational psychologist or had a recognised qualification based on standards from the British Dyslexia Association.

3.2.4.3 Measures and Materials

The measures and materials used in the current experiment were identical to those used in *Experiment 1*. See Chapter-2 for a summary.

3.2.4.4 Procedure

The procedure used in the current experiment was identical to that of *Experiment 1*. See Chapter-2 for a summary.

3.2.5 Results

3.2.5.1 Descriptive Statistics for English Readers with Dyslexia

Number of correct responses were recorded for each participant on each of the WMLS III subtests (Woodcock, Alcarado, & Ruef, 2017). Mean raw scores and standard deviations for each reading ability are displayed in Table 15.

Table 15. Descriptive Statistics for Reading Ability Scores for English Readers with Dyslexia

Subtests	*N* Items	Range	Mean	SD
Language Comprehension	39	24 - 38	30.08	4.29
Vocabulary Knowledge	56	36 - 49	43.46	3.67

Reading Behaviour Between a Consistent and an Inconsistent Orthography

Decoding Skills	76	65 - 74	67.69	2.46
Reading Comprehension	52	38 - 47	44.15	3.18

3.2.5.2 Group Comparisons between English Readers with Dyslexia and without Dyslexia (*Experiment 1* in Chapter-2)

A set of four independent t-tests with Bonferroni corrected alphas of .013 were computed to investigate Hypothesis-5 and test whether each of these scores for the current sample of dyslexic participants were significantly different from the scores of the typically developed English readers measured in *Experiment 1* (Chapter-2). The purpose of this analysis was to examine whether the participants who had been diagnosed with dyslexia had significantly poorer decoding scores, but relatively similar language comprehension scores compared to the age-matched readers without dyslexia. The dyslexic readers and the readers without dyslexia from *Experiment 1* were matched on age, and an independent samples t-test confirmed that there was not a significant age difference $t(66) = 3.25$, $p = .469$.

Decoding Skills There was a significant difference in decoding scores between skilled English readers and the dyslexic readers $t(66) = 2.83$, $p < .01$. On average, the readers without dyslexia had significantly higher decoding scores ($M = 70.19$, $SD = 2.93$) than the dyslexic readers ($M = 67.69$, $SD = 2.47$).

Language Comprehension There was not a significant difference in language comprehension scores between the readers without dyslexia and the dyslexic readers ($t(66) = 1.05$, $p = .299$). The readers without dyslexia had similar language comprehension scores ($M = 28.87$, $SD = 3.59$) compared to the dyslexic readers ($M = 30.08$, $SD = 4.29$).

Reading Behaviour Between a Consistent and an Inconsistent Orthography

Vocabulary Knowledge No significant differences were found for vocabulary scores between the two groups ($t(66) = 1.77$, $p = .082$). The readers without dyslexia had similar vocabulary scores ($M = 41.82$, $SD = 2.80$) compared to the dyslexic readers ($M = 43.46$, $SD = 3.67$).

Reading Comprehension There was not a significant difference in reading comprehension scores between the readers without dyslexia and the dyslexic readers ($t(66) = 0.50$, $p = .619$). The readers without dyslexia had similar reading comprehension scores ($M = 43.63$, $SD = 3.39$) compared to the dyslexic readers ($M = 44.15$, $SD = 3.18$).

3.2.5.3 Correlations Across Reading Skills in English Readers with Dyslexia

To test the extent to which each of these components were related (Hypothesis-1), and as was conducted in *Experiment 1* (Chapter-2), the dyslexic readers' scores from the WMLS III (Woodcock, Alcarado, & Ruef, 2017) were correlated with Bonferroni corrected alpha levels of 0.013. As shown in Table 16, there was a significant positive correlation between language comprehension scores and vocabulary knowledge scores, $r(14) = .91$, $p < .001$, and reading comprehension scores $r(14) = .76$, $p < .001$, but not decoding scores ($r(14) = .44$, $p = .136$). There was also a significant positive correlation between vocabulary knowledge scores and reading comprehension scores $r(14) = .76$, $p < .001$, but not decoding scores ($r(14) = .24$, $p = .432$). Finally, there was no significant correlation between decoding scores and reading comprehension scores ($r(14) = .21$, $p = .494$).

Table 16. Correlations of Language Abilities for English Readers with Dyslexia

	Language Comprehension	Vocabulary Knowledge	Decoding
Language Comprehension			
Vocabulary Knowledge	.91***		
Decoding	.44	.24	
Reading Comprehension	.76***	.76***	.21

Notes: correlation is significant at the *p* > .001***

These correlations will be explored as regressions in the following sections especially with reference to the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990). Since most of these measures were highly correlated with one another (see Table 16), we also tested for multicollinearity using the variance inflation factor (VIF). A high degree of multicollinearity poses a problem to the regression because it increases the variance of the regression coefficients, making them unstable. A VIF over 5 indicates high correlation and is generally suggested as a cut-off point (e.g., Simon, 2009). All variables had VIFs < 5, indicating that collinearity was not a problem.

3.2.5.4 Regression Analysis for English Readers with Dyslexia

To test Hypothesis-2, simple linear regressions were calculated to investigate which of the component skills, i.e., decoding skills or language comprehension skills predicted reading comprehension separately. As shown in Figure 17, it was found that D (decoding) did not significantly predict RC (reading comprehension) ($t(14) = 0.71$, $p = .494$, $R^2 = 0.21$).

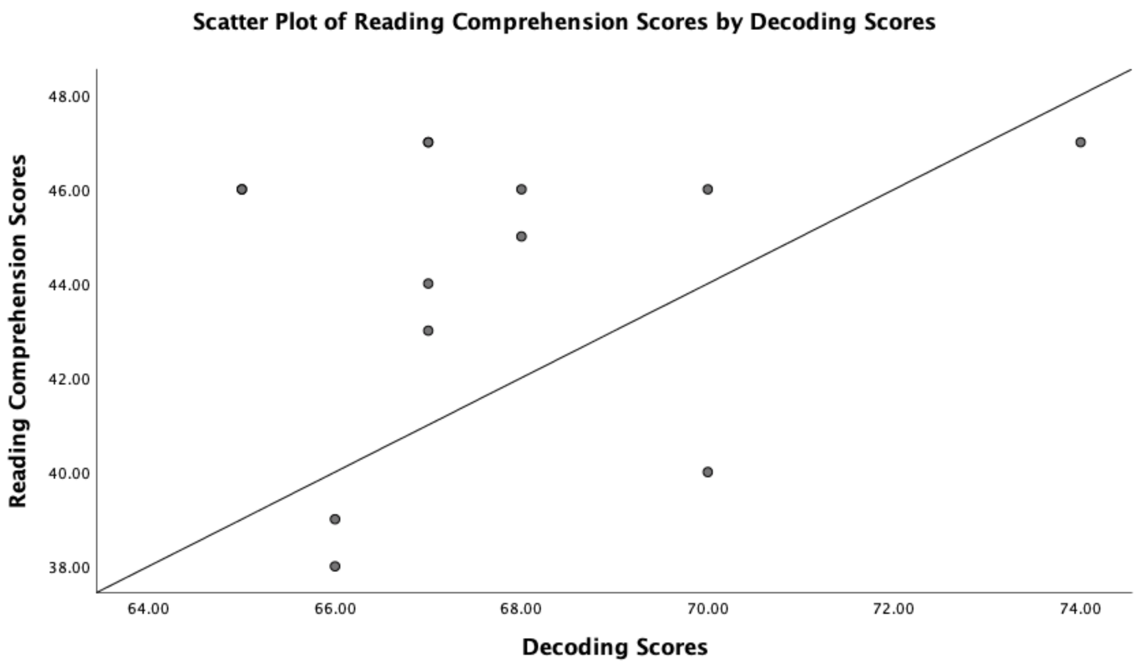

Figure 17. Correlation between Language Comprehension Scores and Reading Comprehension scores for English Readers with Dyslexia

As shown in Figure 18, language comprehension was a significant predictor of reading comprehension for English $t(14) = 3.82$, $p < .001$, $R^2 = 0.57$. To be exact, the model accounted for 57% of the variance in reading comprehension and predicted that reading comprehension scores would increase by 0.56 points for each additional analogy point score.

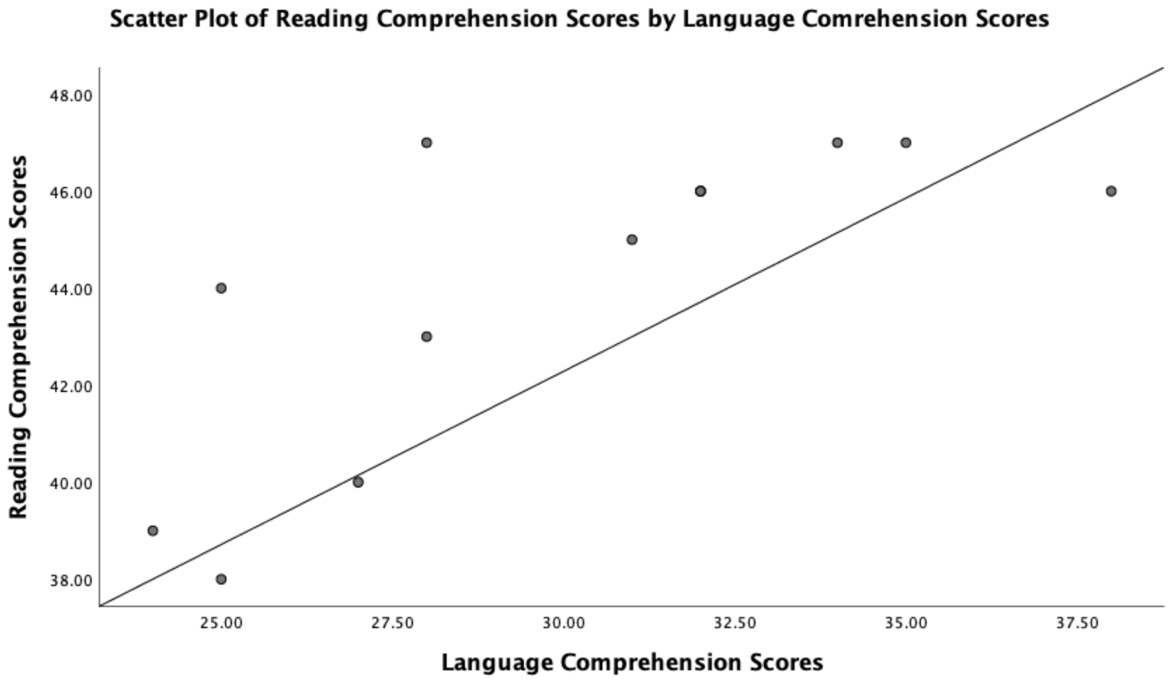

Figure 18. Correlation between Language Comprehension Scores and Reading Comprehension Scores for English Readers with Dyslexia

Next, the pattern of correlations among each reading ability (decoding and language comprehension) was examined using hierarchical regressions to predict reading comprehension.

A hierarchical regression examined whether language comprehension and decoding predicted reading comprehension better than language comprehension alone (Table 17). In Model 1, the overall model was significant $F(1,13) = 14.61$, $p < .001$, $R^2 = 0.57$, such that language comprehension explained 57% of the variation in reading comprehension. Adding decoding to the model did not produce a significant improvement on Model 1, ($\Delta F(1,12) = 0.44$, $p = .522$). However, Model 2 was significant overall $F(2,12) = 7.15$, $p < .05$, $R^2 = 0.59$, and now explained 59% of the variation in reading comprehension ($\Delta R^2 = 2\%$). As shown in Table 17, language comprehension (β = .82) emerged as a stronger predictor of reading comprehension than decoding (β = .15), which was not a significant predictor in this model $p = .522$.

Table 17. Beta Weights in Hierarchical Regression Model Predicting Reading Comprehension with the SVR Component Skills for English Readers with Dyslexia

		B (SE)	**β**	***t***	***p***
Model 1	Constant	27.29 (4.45)			
	Language Comprehension	.56 (.15)	.76	3.82	.001
Model 2	Constant	38.92 (18.12)			
	Language Comprehension	.61 (.17)	.82	3.64	.005
	Decoding	.19 (.29)	.15	0.66	.522

* indicates a significant model improvement

3.2.5.5 Simple View of Reading for English Readers with Dyslexia

The SVR formula (Gough & Tunmer, 1986; Hoover & Gough, 1990) was then tested on these data to investigate the predictions of Hypothesis -3. The SVR postulates that the multiplicative combination of decoding and language comprehension will be a better predictor of reading comprehension than the linear combination of decoding and language comprehension.

First, the product term of decoding and language comprehension was computed, and a subsequent linear regression was conducted to test the (Decoding x Language Comprehension) product model as a predictor of reading comprehension. As shown in Figure

19, the regression revealed that the product model significantly explained 50% of variance in reading comprehension for English readers $t(14) = 7.23$, $p < .001$, $R^2 = 0.50$.

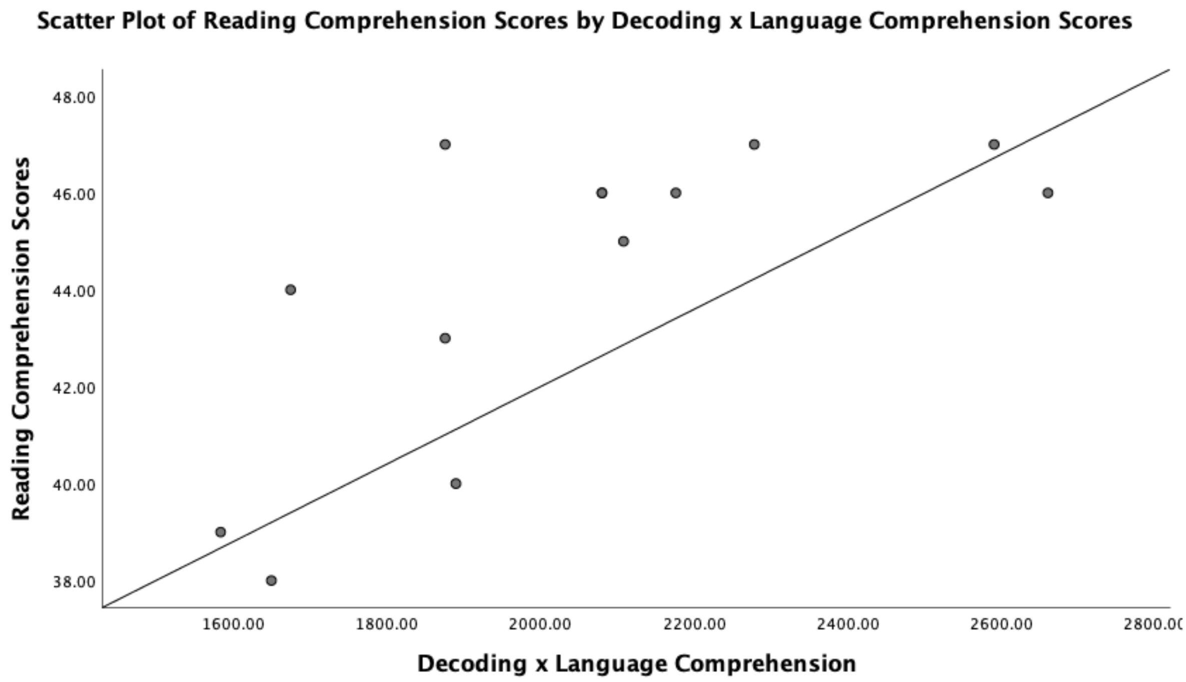

Figure 19. Correlation between the Product of Decoding and Language Comprehension Scores and Reading Comprehension Scores for English Readers with Dyslexia

Next, multiple regressions examined whether the product model would predict unique variance over the linear model of the SVR (Gough & Tunmer, 1986) and are depicted in Table 18. Decoding and language comprehension were entered singly in the first two steps of regressions as an additive mode with reading comprehension as the outcome variable. The additive model was significant $F(2,12) = 7.15$, $p < .01$, $R^2 = .59$, such that this model explained 59% of the variation in reading comprehension. The addition of the product term as a third step in the regression model yielded an overall significant model, $F(3,12) = 4.53$, $p < .05$, $R^2 = .60$, and accounted for an additional 1% of variance, however this increase was not significant ($\Delta F(1,12) = 0.29$, $p = .602$).

When the same procedure was done in reverse, the product model alone was significant $F(2,12) = 10.85$, $p < .01$, $R^2 = .50$, and the addition of the decoding and language comprehension in the next steps accounted for a non-significant ($\Delta F(2,12) = 1.19$, $p = .349$) additional 10% of the variance in reading comprehension.

Table 18. Beta Weights in Multiple Regression Model Predicting Reading Comprehension Decoding and Language Comprehension for English Readers with Dyslexia

		B (SE)	**β**	***t***	***p***
Model 1	Constant	38.92 (18.12)			
	Language Comprehension	.61 (.17)	.82	3.64	.005
	Decoding	.19 (.29)	.15	0.66	.522
Model 2	Constant	64.43 (192.20)			
	Language Comprehension	3.74 (5.80)	5.04	.65	.535
	Decoding	1.34 (2.85)	1.03	.47	.650
	Product (D x LC)	.046 (.086)	4.86	.54	.602
Model 1	Constant	30.45 (4.21)			
	Product (D x LC)	.007 (.00)	.705	3.29	.007
Model 2	Constant	64.43 (192.20)			
	Language Comprehension	3.74 (5.80)	5.04	.65	.535
	Decoding	1.34 (2.85)	1.03	.47	.650
	Product (D x LC)	.046 (.086)	4.86	.54	.602

* indicates a significant model improvement

3.2.5.6 Vocabulary Knowledge for English Readers with Dyslexia

Vocabulary knowledge has been influential additions to the SVR model in previous research (Binder et al., 2017; Braze et al., 2007; Vellutino et al., 2007; Ouellette & Beers 2010; Tunmer & Chapman, 2012). Thus, vocabulary knowledge was added to the previous models to investigate Hypothesis-4 and determine whether this skill could predict reading comprehension above and beyond the component skills in the SVR, i.e., decoding and language comprehension.

First, a simple linear regression was calculated to see whether vocabulary knowledge predicted reading comprehension on its own. As shown in Figure 20, a simple linear regression revealed that vocabulary knowledge was a significant predictor of reading comprehension on its own $t(14) = 3.85$, $p < .001$, $R^2 = 0.57$. To be exact, the model accounted for 57% of the variance in reading comprehension.

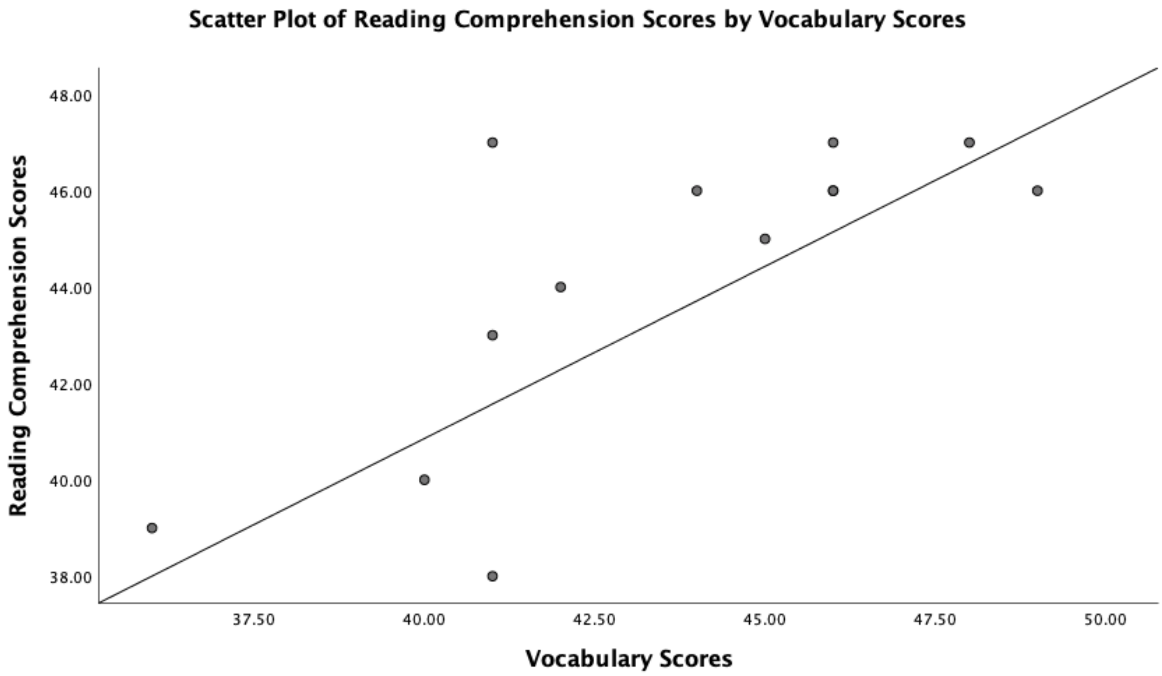

Figure 20. Correlation between Vocabulary Knowledge Scores and Reading Comprehension Scores for English Readers with Dyslexia

Next, vocabulary knowledge was added to the previous hierarchical models which included decoding and language comprehension. Vocabulary knowledge was added as a third step was included to test whether this skill would predict reading comprehension scores above and beyond decoding and language comprehension scores (Table 19). Model 3 did not significantly improve upon Model 2, ($\Delta F(1,13) = 0.31$, $p = .589$), however, Model 3 was significant overall $F(1,13) = 4.55$, $p < .05$, $R^2 = 0.60$, and explained 60% of the variance in reading comprehension ($\Delta R^2 = 1\%$). As shown in Table 19, none of the variables emerged as significant predictors in this model.

Table 19. Beta Weights in Hierarchical Regression Model Predicting Reading Comprehension with Three Reading Abilities for English Readers with Dyslexia

		B (SE)	**β**	***t***	***p***
Model 1	Constant	27.29 (4.45)			
	Language Comprehension	.56 (.15)	.76	3.82	.001
Model 2	Constant	38.92 (18.12)			
	Language Comprehension	.61 (.17)	.82	3.64	.005
	Decoding	.19 (.29)	.15	0.66	.522
Model 3	Constant	28.34 (26.64)			
	Decoding	.11 (.34)	.09	.329	.750
	Language Comprehension	.37 (.46)	.50	.798	.445
	Vocabulary Knowledge	.28 (.50)	.32	.560	.589

* indicates a significant model improvement

These same steps were then conducted in reverse, and a hierarchical regression was performed examining whether vocabulary knowledge and language comprehension predicted reading comprehension better than vocabulary knowledge alone (Table 20). Since decoding was not significant in any of the models, it was not included. In Model 1, the overall model was significant $F(1,13) = 14.79$, $p < .01$, $R^2 = 0.57$, such that vocabulary knowledge explained 57% of the variation in reading comprehension. Adding language comprehension to the model did not produce a significant improvement on Model 1, ($\Delta F(1,13) = 0.60$, $p = .456$), however, overall Model 2 was significant $F(2,12) = 7.43$, $p < .01$, $R^2 = 0.55$, and now explained 59% of the variation in reading comprehension ($\Delta R^2 = 2\%$). As shown in Table 20, neither variable emerged as a significant predictor.

Table 20. Beta Weights in Reverse Hierarchical Regression Model Predicting Reading Comprehension with Three Reading Abilities for English Readers with Dyslexia

		B (SE)	**β**	***t***	***p***
Model 1	Constant	15.56 (7.46)			
	Vocabulary Knowledge	.67 (.17)	.69	6.63	.003
Model 2	Constant	20.23 (9.70)			
	Vocabulary Knowledge	.35 (.43)	.41	0.82	.430
	Language Comprehension	.29 (.37)	.38	0.76	.456

* indicates a significant model improvement

3.2.6 Discussion

The aim of *Experiment 3* was to measure the extent to which the SVR components (i.e., decoding and language comprehension) (Gough & Tunmer, 1986; Hoover & Gough, 1990) may contribute to variance in reading comprehension in a sample of readers of an inconsistent orthography diagnosed with dyslexia. The current experiment also measured the role of vocabulary as an additional factor contributing to reading comprehension. Of further interest was to investigate the extent to which these patterns of scores and their contributions to reading comprehension in a sample of readers with dyslexia differ from an age-matched group of adult readers of English without dyslexia. For these reasons, four measures of reading skills (decoding, vocabulary knowledge, language comprehension and reading comprehension) were measured in a sample of adult readers of English, an inconsistent language, diagnosed with dyslexia. These measures allowed for an investigation of the SVR model, and a group comparison of the age-matched adult English readers without dyslexia who had participated in *Experiment 1* (Chapter-2).

Overall, the dyslexic readers in the current sample scored significantly poorer than the age-matched readers without dyslexia on decoding scores. There was no significant difference between the dyslexic readers and the age-matched readers without dyslexia on measures of language comprehension, vocabulary knowledge or reading comprehension. The SVR model of reading predicted 59% of variance in dyslexic reading comprehension, with language comprehension emerging as the only significant predictor. Decoding scores in the current sample were poor and did not predict variance in reading comprehension. The additive model of the SVR predicted a higher proportion of variance in reading comprehension (59%) than the multiplicative model (50%), however hierarchical regression analyses indicated both models were equally adequate in accounting for variance in dyslexic reading. Vocabulary knowledge was a strong predictor of reading comprehension on its own and accounted for 57% of variance in dyslexic reading comprehension. However, vocabulary knowledge did not account for any unique variance in reading comprehension above and beyond language comprehension or decoding. The implications of each of these findings as well as their position within the current literature will be discussed below.

3.2.6.1 Comparisons with Monolingual English Readers without Dyslexia (Chapter-2)

An initial goal of the current experiment was to compare the dyslexic's scores from measures of reading ability with those that were measured from age-matched adult readers of English without dyslexia in *Experiment 1*. It was expected that since the sample had been formally diagnosed with DD, they would have significantly worse decoding skills compared to readers without dyslexia. Further, if decoding scores were impaired, it was expected that this would impact the reading comprehension scores of the dyslexic participants and that they would score worse than the readers without dyslexia (Hypothesis-1).

As predicted, the dyslexic readers scored significantly worse than readers without dyslexia exclusively on the measure of phonological decoding. Further, the dyslexic readers in the current sample did not score significantly worse on measures of language comprehension or vocabulary compared to the readers without dyslexia, and interestingly, though it was not significant, the dyslexic readers' mean scores on these constructs were slightly higher than the readers without dyslexia. These findings accord with the evidence presented in the literature that decoding and language comprehension skills are distinct, and that dyslexia is specifically characterised by poor decoding skill while specific language impairment is characterised by poor language comprehension skills (Bishop & Snowling, 2004; Gough & Tunmer, 1986; Perfetti, 1985; Snowling, 2000a; Stanovich, 1991; Vellutino, 1979, 1987; Vellutino et al., 1994; Vellutino, Scanlon, & Chen, 1995a; Vellutino et al., 1996). Thus, the current findings support the notion that these readers with dyslexia have deficits primarily in phonological decoding.

These results make sense within the Phonological Deficit Hypothesis (Bradley and Bryant, 1978; Brady and Shankweiler, 1991; Snowling, 1981; Vellutino, 1979) and accord with the bulk of the literature that claims dyslexic reading is characterized specifically by problems with decoding and phonological processes (e.g., Hulme et al., 2012; Melby-Lervåg, Lyster &

Hulme, 2012; Share & Stanovich, 1995; Snowling, 1995; Snowling, Nation, Moxham, Gallagher & Frith, 1997; Vellutino et al., 2004).

According to the SVR if either decoding or language comprehension is impaired, reading comprehension will also be impaired. Contrary to these predictions however, there was no significant difference between these groups on the measure of reading comprehension. Similar evidence has been reported that university students with dyslexia do not show significantly poorer reading comprehension skills than age-matched typically developing readers (Bruck, 1990; Lefly & Pennington, 1991; Miller-Shaul, 2005; Parrila, Georgiou, & Corkett, 2007), this may particularly be the case in untimed reading comprehension measures (Lesaux, Pearson, & Siegel, 2006). For example, Jackson and Doellinger (2002) identified a group of 6 students who demonstrated very poor decoding skills but demonstrated average or even above-average reading abilities compared to typically developing readers. Jackson and Doellinger subsequently termed this group ‘resilient readers’ indicating that despite poor decoding skills, they were able to attain good text-reading skill.

Bishop and Snowling (2004) suggested that readers with dyslexia may compensate for poor word recognition and decoding processes by relying more on their available unimpaired cognitive resources to offset their decoding difficulties. Specifically, they suggest that readers with dyslexia may be able to rely on semantics or contextual cues to support the decoding process (e.g., Elbro & Arnbak, 1996; Que´mart & Casalis, 2015; Snowling, 2000). Similarly, measures of language comprehension have been found to account for a large proportion of variance in dyslexic reading comprehension (e.g., Ozernov-Palchik et al., 2021; Ransby & Swanson, 2003). These findings are inconsistent with the prediction of the SVR that the rate of improvement in reading comprehension due to improvement in language comprehension is not constant but is contingent upon an increase in decoding skill with slopes increasing in magnitude from a floor of zero. Both language comprehension and reading comprehension were not significantly different between readers with and without dyslexia, however decoding was significantly poorer for readers with dyslexia. Thus, language comprehension may not be contingent upon the level of decoding skill, but rather may reflect an additive relationship to reading comprehension. This conclusion was further supported in the current study from the finding that the additive model was adequate in accounting for variance in both dyslexic and typically developing reading comprehension. In the next section, we will discuss how each of these measures relate to reading comprehension in the current sample of adult readers with dyslexia.

3.2.6.2 The Simple View of Reading in Dyslexic Readers

The predominant goal of the current experiment was to investigate the relationship of the component skills from the SVR, decoding and language comprehension to reading comprehension in a sample of adult readers with dyslexia. To briefly review, it was expected decoding and language comprehension would not be correlated with each other but would be correlated with reading comprehension (Hypothesis-1*)*. Further, it was expected that the language comprehension scores should be better than decoding scores at predicting reading comprehension scores (Hypothesis-2).

Results revealed that dyslexic readers' language comprehension scores significantly and largely correlated with reading comprehension (r = .76), but not with decoding, as expected. These results align with previous studies that demonstrate a behavioural dissociation for readers with dyslexia between decoding skills and language comprehension skills (e.g., Bishop & Snowling, 2004). The results from the current experiment suggest that language comprehension skills in the current sample of adult readers with dyslexia were relatively intact compared to poorer decoding skills and thus contribute more to reading comprehension than decoding. This notion was confirmed by the subsequent regression analyses. Dyslexic readers’ language comprehension could account for 57% of the variance in reading comprehension on its own. These results also accord with previous research and the findings from *Experiment 1* (Chapter-2) that demonstrate that as readers gain skill, language comprehension exerts a greater influence than decoding to reading comprehension. (Caravolas et al., 2019; Barnes & Kim, 2016; Goswami, 2002; Gough, Hoover, & Peterson, 1996; Gough & Tunmer, 1986).

Somewhat unexpectedly, decoding skills did not significantly correlate or predict reading comprehension scores at all. Decoding scores only accounted for a non-significant 21% of reading comprehension. Further, adding decoding to the regression model after language comprehension did not significantly improve model fit. A common finding among the literature is that the relative influence of decoding to reading comprehension decreases with age compared to the influence of language comprehension, which tends to increase (e.g., Curtis, 1980; Caravolas et al., 2019; Barnes & Kim, 2016; Goswami, 2002; Gough & Tunmer, 1986; Kendeou, Savage, & van den Broek, 2009). For example, Tilstra et al. (2009) measured decoding, language comprehension and reading comprehension skills in groups of students in Grades-4, Grade-7, and Grade-9. Results showed that the contribution of decoding to reading comprehension at Grade-4 accounted for 42% of the variance in reading comprehension, but only 13% for Grade-7 readers and 17% for Grade-9 readers. On the other hand, language comprehension accounted for only 19% of variance in reading comprehension in Grade-4, compared to the 35% for students in Grade-7, and 21% for students in Grade-9. The authors note that although the proportions were different for children in Grade-7 and Grade-9, the difference was not statistically significant. However, in the current sample of dyslexic adult readers, decoding did not appear to contribute to any variance in reading comprehension at all.

These results disagree with the predictions of the SVR, which claims that all variation in reading comprehension is a product of decoding and language comprehension. These findings were even more evident when the product model RC = D x LC of the SVR was tested on the current sample. While language comprehension alone significantly accounted for 57% of the variance in reading comprehension, the product model only accounted for 50% of the variance in reading comprehension, indicating that the interaction between language comprehension and decoding weakened the predictive power of language comprehension. Such findings raise questions about the necessity of the decoding component in adult readers with dyslexia. As previously stated, the product model implies that readers need at least some skill in each of the component variables, if there is no skill in either decoding or language comprehension, then there will also be no skill in reading comprehension. Conversely the additive model implies that decoding and language comprehension are sufficient, but not necessary for reading comprehension. In this model, either decoding or language comprehension could be bypassed and still result in successful reading comprehension.

Similar to findings with typically developing adult readers of English, it was expected that the product model would not be significantly better than the additive model at accounting for variance in reading (Hypothesis-3). As expected, in the current sample, the product model accounted for much less variance in reading comprehension (50%) compared to the additive model (59%), however, hierarchical regressions revealed that neither model was a statistically significant improvement over the other, indicating that both models were adequate in explaining the variance in reading comprehension. The finding that both the additive and multiplicative model had comparable predictive power to reading comprehension is similar to findings reported by Savage and Wolforth (2007). On the other hand, Pennington et al. (2012) found that the additive model predicted more variance in dyslexic readers. The difference between the results from the current experiment and the results from Pennington's study is that though the readers in the current sample had a history of dyslexia and poor decoding skills, their reading comprehension skills were not significantly different from age-matched typically developed readers. Conversely, Pennington's sample were younger children with dyslexia who demonstrated poorer reading skills than age matched peers. Thus, a conclusion from the findings from each of these studies and the findings from the current results may be that the multiplicative model of the SVR is better at accounting for variance in good reading comprehension, while the additive model may be better at predicting variance in poor reading comprehension.

If decoding does not significantly contribute to reading comprehension for adult readers with dyslexia, and the additive model of the SVR is a better fit to the data, then this invites the question of whether adult readers with poor decoding skills may develop some compensatory strategy through language comprehension abilities or through some other reading skill to bypass decoding. Indeed, similar findings have been reported that decoding and reading comprehension may not be strongly associated in adults with dyslexia. In the current sample, language comprehension accounted for a large proportion of variance (57%) in reading comprehension, while decoding did not account for any significant variance. The results from the current sample and previous research on monolingual English speakers may suggest that the contribution of the components individually to reading comprehension (RC = D + LC) may better characterize dyslexic reading in an inconsistent orthography rather than the interactive contribution (RC = D x LC), thus suggesting that both decoding and language comprehension skills are not strictly necessary in an inconsistent language for readers to attain some level of skill in reading comprehension. These findings further support the possibility discussed above that those readers with poor decoding skills are able to develop compensatory strategies through language comprehension skills which involve skills with semantic and contextual cues and to some extent, vocabulary (e.g., Bishop & Snowling, 2004; Elbro & Arnbak, 1996; Que´mart & Casalis, 2015; Snowling, 2000). However, since language comprehension skills did not account for all the unique variance in reading comprehension, it is also possible that dyslexic readers rely on other skills to support reading comprehension. For this, we turn our attention now to the role of vocabulary in the SVR model for the current sample of dyslexia readers.

3.2.6.3 The Role of Vocabulary in Dyslexic Reading Comprehension

Recently, studies have shown that a third component, vocabulary knowledge, may also contribute to reading comprehension above and beyond decoding and language comprehension (Binder et al., 2017; Braze Tabor, Shankweiler & Mencl, 2007; Ouellette & Beers 2010; Tunmer & Chapman, 2012; Share, 2004). It was expected that adult readers with dyslexia would have adequate vocabulary skills and that these would contribute to unique variance in reading comprehension (Hypothesis-4*)*. In the current sample, vocabulary knowledge significantly correlated most highly with language comprehension (r = .91), and highly with reading comprehension (r = .76), but similar to the other variables, did not significantly correlate with decoding. A similar pattern was found for the typical adult English readers in *Experiment 1*.

Some studies have found that vocabulary may function as a compensatory device for readers with dyslexia to use to attain adequate reading levels despite poor decoding abilities. For example, Cavalli et al. (2015) demonstrated that despite performing significantly worse on measures of phonological awareness and word recognition, a sample of French (an inconsistent orthography) university students with dyslexia outperformed age-matched typically developing readers on a vocabulary measure of breadth, where participants were asked to match pictures with words presented orally, and depth, where participants were presented with a word orally and asked to define it. In the current sample, although vocabulary knowledge was a significant independent predictor of reading comprehension and predicted 57% of variance in reading comprehension, this skill did not significantly account for any additional variance above and beyond decoding. When the same steps were analysed in reverse in a hierarchical regression however, language comprehension did not account for any significant variance above vocabulary knowledge either. These results indicate that both vocabulary and language comprehension adequately account for variance in reading comprehension in the current sample of adult readers with dyslexia. Similarly, in *Experiment 1*, vocabulary was found to account for a significant additional 11% of variance in reading comprehension above and beyond decoding and language comprehension for the typical adult readers of English.

These findings raise doubts on the predictions of the SVR and suggest that for readers with dyslexia, decoding may not contribute at all to variance in reading comprehension and suggesting that language comprehension may be sufficient on its own for reading comprehension rather than the interaction of decoding and language comprehension. Instead, readers with dyslexia may develop compensatory strategies through language comprehension and vocabulary knowledge to support reading.

3.2.6.4 Limitations and Further Research

Findings from the current experiment are informative and contribute to the understanding of reading skills in readers with dyslexia. However, these results are still limited. First, the relatively small sample size of the dyslexic participants compared to the typically developing readers limits the external validity of these findings. Future research should seek to evaluate the contribution of decoding, language comprehension, and vocabulary knowledge to reading comprehension in a larger sample of readers with dyslexia to improve external validity of the current findings.

Second, although the skills measured in the current experiment contributed to a large proportion of variance in reading comprehension, they failed to account for all the variance in reading comprehension. Thus, this finding suggests that there may be other skills contributing to reading comprehension that were not measured in the current experiment. Further, each of these skills were measured using a single test, which may not have captured the entire range of the skill. Future research may benefit from measuring a larger battery of skills in samples with similar characteristics to elucidate some of the additional factors that may be contributing to variance in reading comprehension.

3.2.6.5 Conclusion

The current experiment used the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990) as a framework for characterizing the developed skills involved in dyslexic reading. Of further interest was to investigate the extent to which these patterns of scores and their contributions to reading comprehension in a sample of readers with dyslexia differ from an age-matched group of adult readers of English without dyslexia.

It was expected that the sample adult readers who had been diagnosed with dyslexia would have impaired decoding skills and because of this, the measured skills would show a different pattern of contribution to variance in reading comprehension than typically developing readers. Particularly, it was expected that language comprehension would account for a higher proportion of variance in reading comprehension. The findings supported these hypotheses.

The dyslexic readers in the current sample scored significantly poorer than the age-matched readers who had been measured in *Experiment 1* on decoding only. There was no significant difference between the dyslexic readers and the age-matched typically developing readers on measures of language comprehension, vocabulary knowledge or reading comprehension. Decoding scores in the current sample were poor and did not predict variance in reading comprehension. The additive model of the SVR predicted a higher proportion of variance in reading comprehension (59%) than the multiplicative model (50%), however hierarchical regression analyses indicated both models were equally adequate in accounting for variance in dyslexic reading. Vocabulary knowledge was a strong predictor of reading comprehension on its own and accounted for 57% of variance in dyslexic reading comprehension. However, vocabulary knowledge did not account for any unique variance in reading comprehension above and beyond language comprehension or decoding.

Overall, these findings do not support the predictions of the SVR and instead suggest that for readers with dyslexia, decoding may not contribute at all to variance in reading comprehension. However, the additive and interactive contribution of decoding to language comprehension does account for some unique variance. Instead, language comprehension may be adequate and sufficient on its own at accounting for most of the variance in reading comprehension in adult readers with dyslexia. The reason for this may be that readers with dyslexia may develop compensatory strategies through language comprehension and vocabulary knowledge to support reading. However, further research in samples with similar characteristics is needed to further elucidate these findings.

3.3 Experiment 4: Eye Movement Patterns in Readers with Dyslexia

3.3.1 Introduction to Eye Movement Patterns in Readers with Dyslexia

The results of *Experiment 3* (Chapter-3) demonstrated a predictive pattern of reading abilities to reading comprehension in a sample of monolingual English readers diagnosed with dyslexia. As was investigated in *Experiment 2* (Chapter-2) with typically developing monolingual English readers, the current experiment aimed to explore the relationship between these measured reading abilities in dyslexic readers and eye movement patterns. A further goal of the current experiment was to compare eye movement patterns of readers with and without dyslexia to gain an understanding of the reading process and the potential consequences of an inconsistent orthography.

Findings from *Experiment 2* (Chapter-2) demonstrated that text properties (length and frequency) as well as individual differences were associated with eye movement patterns in adult readers of English without dyslexia. Thus, it follows that eye movement patterns of readers with dyslexia would differ from typical readers without dyslexia. Indeed, compared to typically developing readers of English reading the same text, eye movement patterns of dyslexic readers are reported to be less consistent, and tend to be much more variable in both size and duration of movements. For example, it is commonly reported that dyslexic readers make more frequent and shorter saccades, more frequent and longer fixations, and proportionally more regression than typically developing readers (e.g., Pavlidis, 1985; Rayner, 1998; Rubino & Minden, 1973).

Eye movements may be an especially useful tool to investigate whether reading problems associated with dyslexia may manifest from a visual or phonological deficit (Biscaldi, Fischer & Hartnegg, 2000; Caldani, Gerard, Peyre & Bucci, 2020; Pavlidis,1981; Rayner, 1985; Seassau, Gerard, Bui-Quoc & Bucci, 2014). On the one hand, some researchers suggest that reading problems may occur as a result of poorly executed eye movements, which in turn may be caused by a visual or attentional deficit (e.g., Biscaldi, Fischer, & Aiple, 1994; Eden, Stein, Wood, & Wood, 1994; Pavlidis, 1981, 1983). One convincing study for this hypothesis came from Pavlidis (1981) who found that dyslexic readers demonstrated different eye movement patterns compared to typically developing readers during a non-reading task. In this experiment, readers with dyslexia and typically developing readers were asked to follow a dot on the screen while their eye movements were tracked. Results showed that dyslexic readers made more saccades than the typically developing readers. However, many attempts to replicate the findings that dyslexics demonstrate unique eye movements to typically developing readers using the same non-reading task have failed to support this claim (Biscaldi et al., 1994; Black, Collins, DeRoach, & Zubrick, 1984; Fields, Wright, & Newman, 1993; Olson, Kliegl, & Davidson, 1983; Stanley, Smith, & Howell, 1983). Further, other studies have failed to find differences between typically developing and dyslexic readers' eye movements during other non-reading tasks (Adler-Grinberg & Stark, 1978; Eskenazi & Diamond, 1983; Olson, Conners, & Rack, 1991). For example, Kapoula et al. (2008) investigated eye movements in dyslexic readers and reported that dyslexic readers have poor binocular coordination and saccade coordination when fixating on nontext visual stimuli compared to typically developing readers. These findings suggest the possibility of an oculomotor deficit as a cause of poor reading. However, a subsequent study by the same research group found that when readers with dyslexia were asked to visually explore a space, their saccades, vergence, and combined movements were as good as those of typically developing readers (Bucci, Vernet, Gerard, & Kapoula, 2009). Similar to the aforementioned behavioural studies, research that measures eye movement patterns appears to find weak connections between dyslexia and visual impairments.

In an opposing argument, researchers have suggested that eye movement patterns are not the cause of reading problems, but rather a consequence of poor reading skills (e.g., Ellis & Miles, 1981; Goldberg & Arnot, 1970). Much independent evidence converges to suggest that a phonological processing deficit is a common underlying factor for most readers with DD, and eye movement may simply reflect this difficulty with processing phonological stimuli. There are several findings that may support this conclusion. For example, readers with dyslexia have been found to demonstrate the typical word frequency effect where low-frequency words are fixated longer than high-frequency words (Hyona & Olson, 1995), which demonstrates sensitivity to phonological information in text rather than just visual information. If readers with dyslexia were experiencing a visual problem alone, it might be expected that all words would be affected equally regardless of frequency or familiarity.

Further, it has been suggested that eye movements are closely linked to lexical processing, and that fixations on visual target images may reflect the lexical activation of the word (Rayner, 2009; Tanenhaus, Magnuson, Dahan, & Chambers, 2000). For example, Desroches et al. (2005) measured phonological processes in a sample of children with and without dyslexia using eye tracking methods. Participants were asked to complete an auditory word recognition task while their eye movements were tracked. The children were presented with arrays of four objects and were instructed to look at a target item (e.g., an image of a candle). The objects that surrounded the target were either phonologically unrelated to the target (e.g., tower), or included a cohort distractor that either had the same initial syllable as the target (e.g., candy), a rhyme distractor (e.g., sandal) or both. Both the dyslexic children and the age-matched controls showed slower recognition latencies indicated by slower fixation rates to the target, when presented with a cohort distractor. The control group also demonstrated slower recognition times when a rhyme distractor was present, however, the dyslexic children's eye movements were unaffected by the rhyme distractor. The authors concluded that the children with dyslexia had not processed the rhyme relationship because of poor phonological processing. Similar results have also been reported for adult readers (Allopenna et al., 1998) and suggest that lexical activation occurs even in a non-reading task when objects are presented.

Similar to the conclusions drawn from investigating the Visual Deficit hypotheses of dyslexia, it is possible that deficits in eye movement execution may only occur in a subset of readers with dyslexia. For example, Eden et al. (1994) investigated eye movement patterns among age-matched typically developing readers, age-matched and reading level matched poor readers with dyslexic readers in a non-reading visual task. The children were asked to either fixate a target, look back and forth between two targets, or follow a target with their eyes (smooth pursuit). Fixation stability (measured by presenting a target at 3 different distances so that eyes would have to converge), saccades (for smooth pursuit), and vergence eye movements (a measure of simultaneous movement of both eyes in opposite direction) both were measured. Phonological ability was also assessed using a Pig Latin task, and reading was assessed using a cloze task, a real word reading task, and a nonword reading task. Results from group comparisons demonstrated that fixation stability for small targets, vergence eye movements, and left to right saccades were poorer for dyslexic readers than typically developing readers. However, when the proportions of groups were examined to distinguish between dyslexic readers who had poor eye movement control only, had poor phonological ability only, or both, results demonstrated that all readers with poor vergence (21%) also had a phonological deficit, but 37% of readers had a phonological deficit only. Further, only 12% of the dyslexic readers had poor fixation stability only, while 44% of dyslexic readers had a phonological deficit only, and 13% had both. Phonological ability was also the strongest predictor of reading comprehension compared to the eye movement measures. Similarly, Fischer, Biscaldi, and Otto (1993) found that only a subgroup of 4 adults with dyslexia demonstrated more saccades with shorter fixations during the Pavlidis task. Hawelka and Wimmer (2005) also concluded that although dyslexic readers demonstrated abnormal eye movements compared to typically developing readers, these eye movements were not significantly associated with poorer dorsal stream function as measured by coherent motion detection.

More recently, some researchers have attempted to directly test dyslexic readers' sensitivity to either phonological or visual stimuli. Jones and colleagues (2008) compared the influence of both phonological and visual processing in typically developing and dyslexic adult readers' RAN performance. Participants completed RAN tasks that were either phonologically or visually difficult to process. The phonological condition presented participants with ten pairs of letters in RAN that were either phonologically similar, such as b and v (identical rimes) or dissimilar. The visual condition presented participants with ten pairs of letters in RAN that were visually similar, such as p and q (mirror images) or non-similar. Dyslexic readers were slower than typically developing readers at naming latencies and showed slower processing times as indexed by fixation durations for all trials. Importantly, dyslexic readers were also significantly slower than typically developing readers when letters were either phonologically or visually similar. Thus, demonstrating that dyslexic readers are sensitive to both phonological and visual stimuli, but that eye movements are affected by difficulties with the text, rather than the other way around.

Further evidence that reading difficulties affect eye movement patterns comes from studies demonstrating that eye movements change when readers read outside their appropriate level. For example, Pirozzolo and Rayner (1978) found that when readers with dyslexia read a text that matched their reading level, their eye movements were similar to those of reading-level matched typically developing readers (see also Häikiö et al., 2009, Rayner, 1986). Similarly, research has reported that typically developing readers showed similar characteristics to those of dyslexic readers when they read texts that were difficult for their reading level (Henderson and Ferreira, 1990, Rayner et al., 2010). This converging evidence points to the conclusion that eye movements reflect a reading problem rather than cause a reading problem.

In sum, measuring eye movement patterns during reading might be very useful for identifying the strategy used by readers to decode words and for investigating the characteristics of abnormal reading patterns in readers with DD. Overall, it appears as though there is weak evidence to support the claim that reading problems may occur as a result of poorly executed eye movements, which in turn may be caused by a visual or attentional deficit. Instead, phonological processes, which are poor in readers with dyslexia may drive eye movement patterns. Although most of the evidence suggests that abnormal eye movement patterns in readers with dyslexia likely reflect deficits in phonological processes, rather than serving as the cause of poor phonological processes, the nature of this link is still under debate. Thus, further research investigating the link between eye movement patterns and phonological processes in readers with dyslexia is warranted. A useful way of demonstrating phonological access in readers is to investigate length and frequency effects. Thus, the current thesis will measure these effects in readers with dyslexia while tracking their eye movement patterns. The next section will offer a discussion on research that has investigated length and frequency effects in readers with dyslexia and will demonstrate where there may be gaps in the literature.

3.3.1.1 Length and Frequency Effects in Developmental Dyslexia

Investigating length and frequency effects in eye movements may be a particularly useful way to compare visual theories and phonological theories of dyslexia. While the length of a word may be considered a visual property, frequency is purely a linguistic variable. Thus, variation in eye movement patterns between low-frequency and high-frequency words for dyslexic readers particularly in early eye movement measures which may reflect phonological processing (i.e., first fixation duration and gaze duration), would suggest that eye movements are sensitive to indeed reflecting problems with linguistic information rather than demonstrating some oculomotor deficit.

Despite extensive research investigating length and frequency effects in typically developing native-English readers and their eye movements, there are very few studies that have investigated these effects in native-English readers with dyslexia (e.g., Provazza, Giorfe, Adams & Roberts, 2019; Ziegler et al., 2003), and even fewer that have investigated these effects using eye-tracking methods (e.g., Hyona & Olson, 1995). Although it should be noted here that these effects have been investigated in dyslexic readers in other orthographies (e.g., Barca, Burani, Di Filippo & Zoccolotti, 2006; Hawelka et al., 2010; Hutzler & Wimmer, 2004; Juphard et al., 2004; Martens & de Jong, 2006; Suárez-Coalla and Cuetos, 2015; Zoccolotti et al., 2005) and these findings will be further discussed in Chapter-4. Findings suggest that length and frequency effects may be even larger in dyslexic readers compared to typically developing readers because of the inefficient lexical route paired with consistent over-reliance on sub-lexical decoding (e.g., Barca, et al., 2006; Hawelka et al., 2010).

Recently, Provazza, Giorfe, Adams, and Roberts (2019) investigated length effects in a sample of native-English adult participants with DD compared to typically developing readers. Participants were asked to read aloud words and nonwords that were manipulated for length, and in the case of real words, frequency. Dependent measures included reaction times and accuracy. Overall, the typically developing readers were faster and more accurate than the dyslexic readers. In the word reading condition, both length and frequency effects were found for the dyslexic group only, however, the length effects were only found for low-frequency words. Length effects were also found in nonword reading for the dyslexic participants only. These results were interpreted to indicate that adult readers with dyslexia continued to over-rely on a sub-lexical reading strategy while reading. Further, since no length effect emerged for high-frequency words, readers with dyslexia may be able to process larger units when words are familiar, but predominantly rely on smaller units to decode words that are unfamiliar. These results are also in line with the Psycholinguistic Grain Size Theory (Ziegler and Goswami, 2005), previously discussed.

Even fewer studies have examined length and frequency effects of native-English dyslexics and typically developing readers' eye movements. In an early study, Hyona and Olson (1995) measured eye movement patterns from a group of children with dyslexia and a younger group of typically developing children who were matched for reading-level. Participants were asked to read texts aloud embedded with targets manipulated for length and frequency, while their eye movements were monitored. The texts chosen were above the participants' reading level so that a comparison could be made between verbalised reading errors and eye movements. Four types of verbalised reading errors were distinguished; (1) the target word was substituted by a nonword response, (2) the target word was replaced by another word, (3) a morphological reading error (e.g., *headed* was read as *head*), and (4) no response (i.e., the target was not read aloud).

Frequency effects but not length effects, were found for first fixation durations, and this effect was not significantly larger for the dyslexic readers than the typically developing readers. Both length and frequency effects were found for gaze durations, and second-pass reading times; however, this effect was only significantly larger for the dyslexic readers in second-pass reading times. Nonword substitution errors were the most common types of errors for both groups, but the dyslexic participants made more reading errors than the typically developing children. Nonword substitution errors were associated with more first-pass fixations for both groups. Results were interpreted to indicate that eye movements are a reflection and not a cause of reading difficulties since both dyslexic readers and typically developing readers experienced demonstrated similar eye movement patterns associated with errors. Although these results are informative, since participants were asked to read a text that was intended to be above their reading level to elicit some degree of reading error, if both groups of readers had difficulties processing the text, then the eye movements may not have been sensitive to the particular phonological impairments of the dyslexic readers. Similarly, as previously pointed out, reading-level matched group comparisons have demonstrated that younger typically developing children, may demonstrate similar reading patterns to older dyslexia readers (Pirozzolo & Rayner, 1979). Thus, an investigation of these eye movement patterns in adult readers with dyslexia compared to age-matched readers is warranted.

To our knowledge, these specific eye movement measures have not been investigated in adult readers with dyslexia. However, these eye movement measures may be particularly useful at revealing the time-course of length and frequency effects by demonstrating whether early or late eye movement measures are affected by these word properties. For these reasons, these eye movement measures will be investigated in a sample of adult readers with dyslexia. These eye movement measures were also investigated previously in a sample of typically developing adult readers in *Experiment 2* and will be compared to those of the dyslexic readers in the current experiment.

3.3.2 Experiment 4: The Current Experiment

Phonological deficits associated with dyslexia have been found to persist into adulthood (e.g., Gallagher, Laxon, Armstrong & Firth, 1996; Hatcher, Snowling & Griffiths, 2002; Snowling, 1980; Snowling, et. al., 1997), thus, it is reasonable to expect that such phonological impairments may still be observed during reading. These effects may be more likely to occur in the eye movements that reflect early lexical access (i.e., first fixation durations and gaze durations) rather than in eye movements that reflect later processes (i.e., go-past times and total reading times). However, surprisingly few studies have examined length and frequency effects using these eye movement measures between adult dyslexic readers and typically developing or skilled readers of English. Adults with dyslexia may be a particularly informative group because in the current sample (*Experiment 3*), although decoding skills were significantly poorer, language comprehension, vocabulary and reading comprehension scores did not significantly differ from the monolingual English readers without dyslexia from *Experiment 1* (Chapter-2), and in fact, dyslexic readers score slightly better than the readers without dyslexia. For these reasons, the current experiment aimed to determine whether adult readers diagnosed with dyslexia engage in unique eye-movement patterns when reading whole sentences for meaning in English. The SVR continues to be a supported model to account for individual variation in reading comprehension. In *Experiment 3*, the SVR accounted for 59% of variance in reading in the current group of readers with dyslexia. The SVR is particularly useful at reflecting deficits in phonological decoding in readers with dyslexia. If eye movement patterns reflect lexical access and reflect poor decoding skills (Desroches, et al., 2005; Rayner, 2009; Tanenhaus, Magnuson, Dahan, & Chambers, 2000), then it is reasonable to assume that eye movement patterns may also reflect the component skills in the SVR. A comparison of both online and offline tasks is useful to determine the extent to which phonology may affect eye movement patterns in adult readers diagnosed with DD compared to age-matched readers without dyslexia.

Reading strategies, and thus eye movement patterns, may be affected by the stage of development a reader is in, as well as the consistency of the orthography being read. The first goal of the current experiment was to produce an on-line record of reading strategies measured by eye movements employed by adult readers with dyslexia as they process full sentences while being instructed to also extract meaning. These results were compared to age-matched typically developing readers who were measured in *Experiment 2*. A second aim of the current experiment was to compare these online measures with the component measures from the SVR that were measured offline. These analyses will provide a further understanding of developed component skills and their relationship to cognitive processes involved in reading as measured by eye movement strategies.

3.3.2.1 Hypotheses

The current experiment aimed to investigate the following hypotheses:

1. According to eye movement research, dyslexic readers typically exhibit more frequent and longer fixations, and proportionally more regressions than typically developing readers (e.g., Pavlidis, 1985; Rayner, 1998; Tinker, 1965). Following this, it was expected that the current sample of adult readers with dyslexia would demonstrate the same difference compared to age-matched typically developing readers. It was also expected that readers with dyslexia would exhibit slower early and late measures of reading.

2. Evidence suggests that frequency effects may affect early eye movement measures while length effects may affect late eye movement measures because of the inefficient lexical procedure paired with an over-reliance on sub-lexical decoding (Hawelka et al., 2010). For the current sample of adult readers with dyslexia it was expected that their eye movement patterns would be sensitive to both length and frequency effects; however, it was expected that the time-course of these effects would differ. Specifically, it was expected that frequency effects would be most sensitive in early measures of lexical access, while length effects would be most sensitive in late eye movement measures.

3. Since length and frequency effects have been found to be larger for poorer readers or dyslexic readers compared to typically developing readers (e.g., Hyona & Olson, 1995; Joseph, Nation & Liversedge, 2013; Provazza, Giorfe, Adams & Roberts, 2019), it was also expected that these effects would be larger for the current sample of readers with dyslexia compared to age-matched typically developing adults.

4. Similar to the age-matched typically developing readers (*Experiment 2),* for a sample of adult readers with dyslexia, it was expected that decoding skills would correlate with early eye movement measures of lexical access as well as fixation duration, fixation and saccade count while language comprehension and reading comprehension were expected to correlate with the late eye movement measures of

lexical access. It was also expected that vocabulary should be correlated with these eye movement measures particularly for low-frequency words.

3.3.3 Methods

3.3.3.1 Participants

The same 14 participants from *Experiment 3* in the current Chapter participated directly afterwards in this experiment.

3.3.3.2 Measures and Materials

The methods and materials were identical to those used in *Experiment 2* (Chapter-2).

3.3.3.3 Apparatus

The apparatus was identical to that used in the pilot experiment and *Experiment 2* (Chapter-2).

3.3.4 Results

After eye-tracking data had been collected the same cleaning procedure as was used in the pilot experiment was used in the current experiment to remove very short (< 80 ms) or very long fixations (> 1,000 ms)(Inhoff & Radach, 1998; Liversedge, Paterson, & Pickering, 1998). Targets that received no fixation in first-pass reading were excluded from analyses for all measures of processing time. Total data loss was 11.64%.

As with *Experiment 2* (Chapter-2), global eye movement measures (fixation and regression count, fixation duration, and total reading time) were calculated across the whole sentence. The local measures were calculated from long and short high-frequency and low-frequency words These measures included first fixation duration, gaze duration, go-past times and total fixation time (see Table 8 in Chapter-2 for the definitions of each of these measures).

The current experiment investigated eye movement patterns in native English monolingual readers while reading sentences for meaning in English. Before eye movement measures were analysed, the TRUE-FALSE critical comprehension scores for the sentences for each participant were calculated. All participants scored 80% or higher and thus no participant was excluded from analysis.

3.3.4.1 Sentence-Level Measures for English Readers with Dyslexia

Means and standard deviations for each eye movement measure are displayed in Table 21. These scores were calculated based on average scores across the entirety of each sentence.

Table 21. Mean Eye-Movement Measures Across Sentences for English Readers with Dyslexia

Measure	Fixation Count	Average Fixation Duration (ms)	Regression Count	Total Reading Time (ms)
Readers with Dyslexia	17.41 (1.54)	202.51 (18.50)	7.02 (0.76)	4513.19 (570.23)
Range	14.17 – 20.02	171.70 – 233.27	5.69 – 8.08	3295.52 – 5139.65

3.3.4.2 Group comparisons for Sentence Level Measures between Monolingual English Readers with Dyslexia and Readers without Dyslexia (*Experiment 2*, Chapter-2)

To compare global reading strategies between readers with and without dyslexia, A set of four independent t-tests with Bonferroni corrected alphas of .013 were computed for fixation count and duration, regression count, and total reading time.

Dyslexic readers exhibited significantly more fixations per sentence $t(67) = 4.26$, $p < .001$ ($M = 17.41$, $SD = 1.54$) than readers without dyslexia ($M = 13.47$, $SD = 2.99$) and more regressions per sentence $t(67) = 4.24$, $p < .001$, ($M = 17.02$, $SD = 0.76$) than readers without dyslexia ($M = 5.38$, $SD = 1.39$). Dyslexic readers also spent significantly longer time reading sentences ($M = 4513.19$, $SD = 570.23$) than readers without dyslexia $t(67) = 4.47$, $p < .001$, ($M = 3510.65$, $SD = 782.57$). However, fixation durations were not significantly shorter ($t(64)$

= 0.35, *p* = .726) for readers with dyslexia (*M* = 202.51, *SD* = 18.50), than readers without dyslexia (*M* = 204.67, *SD* =19.58).

3.3.4.3 Word-Level Measures for English Readers with Dyslexia

To investigate word-level effects on eye movement strategies, a 2 (frequency: low vs high) x 2 (length: long vs short) repeated measures ANOVA was conducted for each of the eye movement measures (First fixation duration, gaze duration, go-past time, and total reading time) with Bonferroni corrected alphas of .013 to investigate the effects of length and frequency. Only significant findings are reported. Mean eye movement measures are tabulated in Table 22.

Table 22Mean Eye-Movement Measures for Frequency x Length for English Readers with Dyslexia

Measure Mean (SD)	First Fixation Duration	Gaze Duration	Go-Past Times	Total Reading Times
HF_Short Words	196.08 (21.59)	241.51 (26.17)	212.69 (45.99)	425.23 (113.39)
LF_Short Words	221.09 (45.27)	284.90 (44.22)	187.32 (33.10)	443.16 (72.07)
HF_Long Words	204.06 (18.44)	237.27 (31.29)	230.68 (26.06)	521.71 (136.14)
LF_Long Words	218.81 (18.62)	299.57 (43.87)	306.53 (64.51)	605.66 (102.35)

There was a significant main effect of frequency for early eye movement measures, but not late eye movement measures. Specifically, as seen in Table 22, shorter first fixation durations $F(1,14) = 4.61$, $p < .01$, and gaze durations $F(1,14) = 21.85$, $p < .001$ were exhibited for high-frequency compared to infrequent words.

There was a significant main effect of length for the late eye movement measures. Specifically, as seen in Table 22, shorter, go-past times $F(1,14) = 24.8$, $p < .01$, and total reading time $F(1,14) = 15.08$, $p < .001$, were exhibited for short compared to long words.

Reading Behaviour Between a Consistent and an Inconsistent Orthography

There were no significant length by frequency interactions for early eye movement measures, nor for total reading time, however these interactions were significant for go-past times. Specifically, there were significant length by frequency interactions for go-past times $F(1,14) = 7.90$, $p = .013$. These interactions indicate that for go-past times, there were no frequency effects for short words, and no length effects for high-frequency words, but there were length effects for low-frequency words.

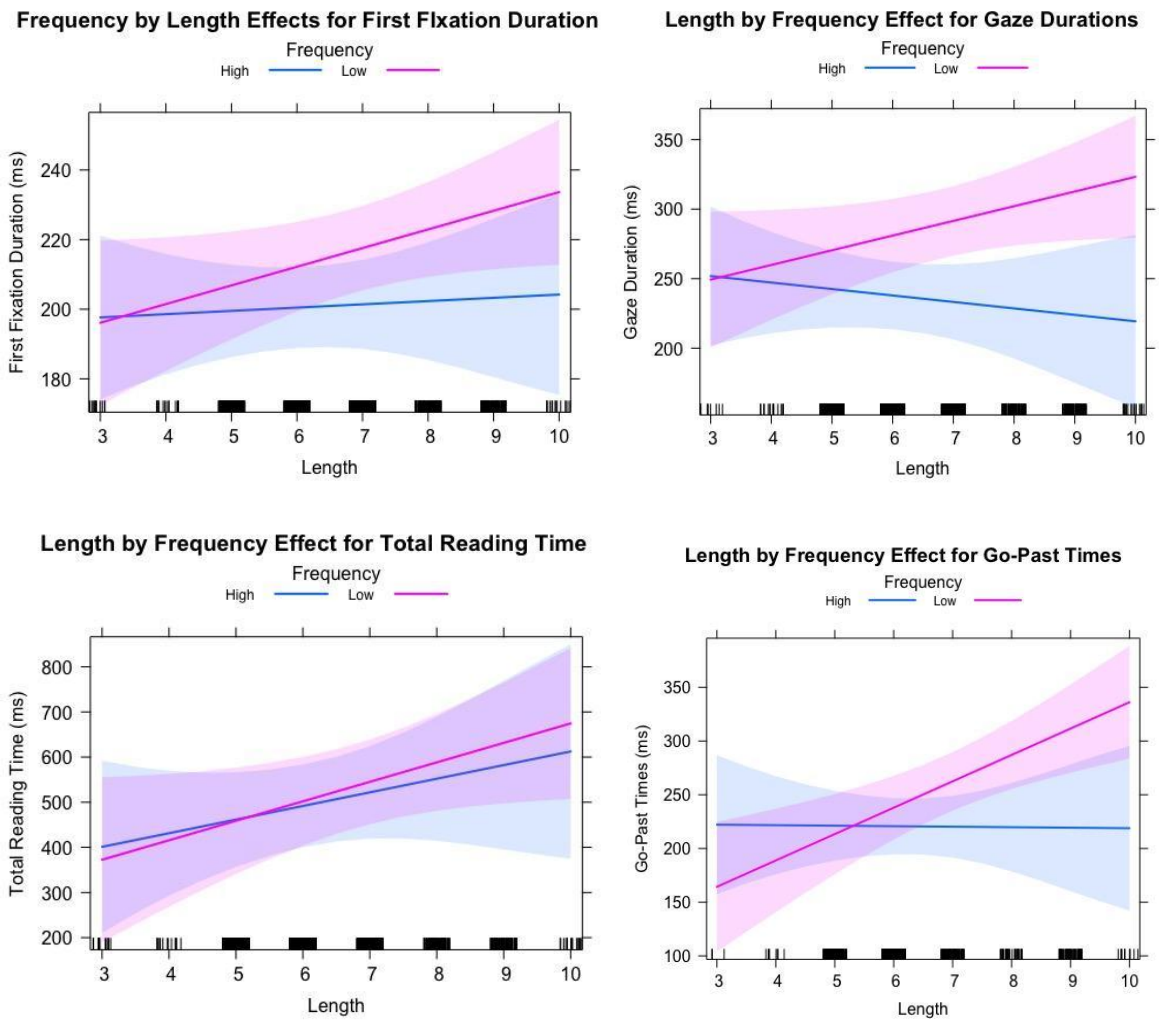

Figure 21, 22, 23, and 24. Frequency and Length effects on Eye Movement Measures for English Readers with Dyslexia

Reading Behaviour Between a Consistent and an Inconsistent Orthography

3.3.4.4 Group comparisons for Sentence Level Measures between Monolingual English Readers with and without Dyslexia (*Experiment 2,* Chapter-2)

To compare local reading strategies between readers with and without dyslexia, A 2 (Length: Short vs. Long) x 2 (Frequency: High vs. Low) x 2 (Group: Dyslexic vs. typically developing) between-subjects ANOVA was calculated for first fixation durations, gaze durations, go-past times, and total reading times with Bonferroni corrected alphas of .013. Only significant effects are reported.

First Fixation Durations There was a main effect of frequency for first fixation durations $F(1,252) = 10.11$, $p < .01$, as seen in Figure 25 first fixation durations were shorter for high frequent words (M = 202.99, SD = 24.93) compared to low-frequency words (M = 217.75, SD = 31.99).

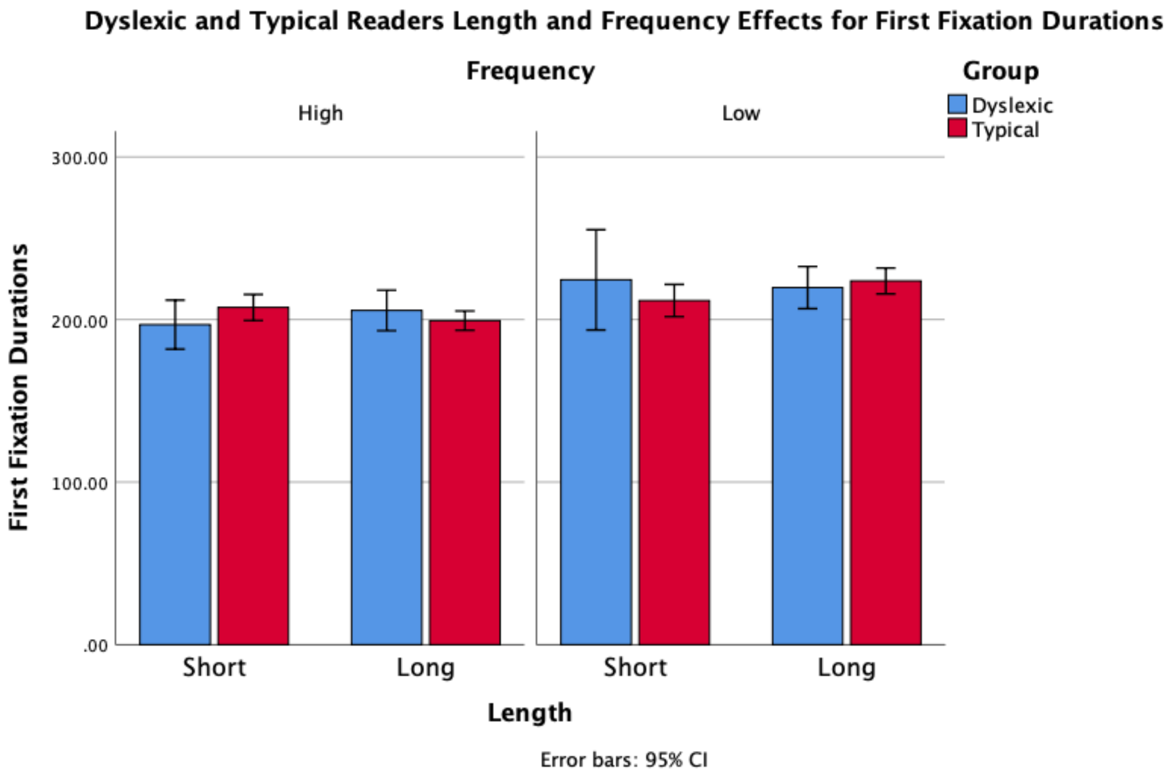

Figure 25. Length and Frequency Effects for First Fixation Durations between Monolingual English Readers with and without Dyslexia

Gaze Durations There was a main effect of frequency for gaze durations *F*(1,252) = 29.30, *p* < .001 as seen in Figure 26, gaze durations were significantly shorter for high frequent words (*M* = 242.25, *SD* = 41.96) compared to low-frequency words (*M* = 283.62, *SD* = 58.89).

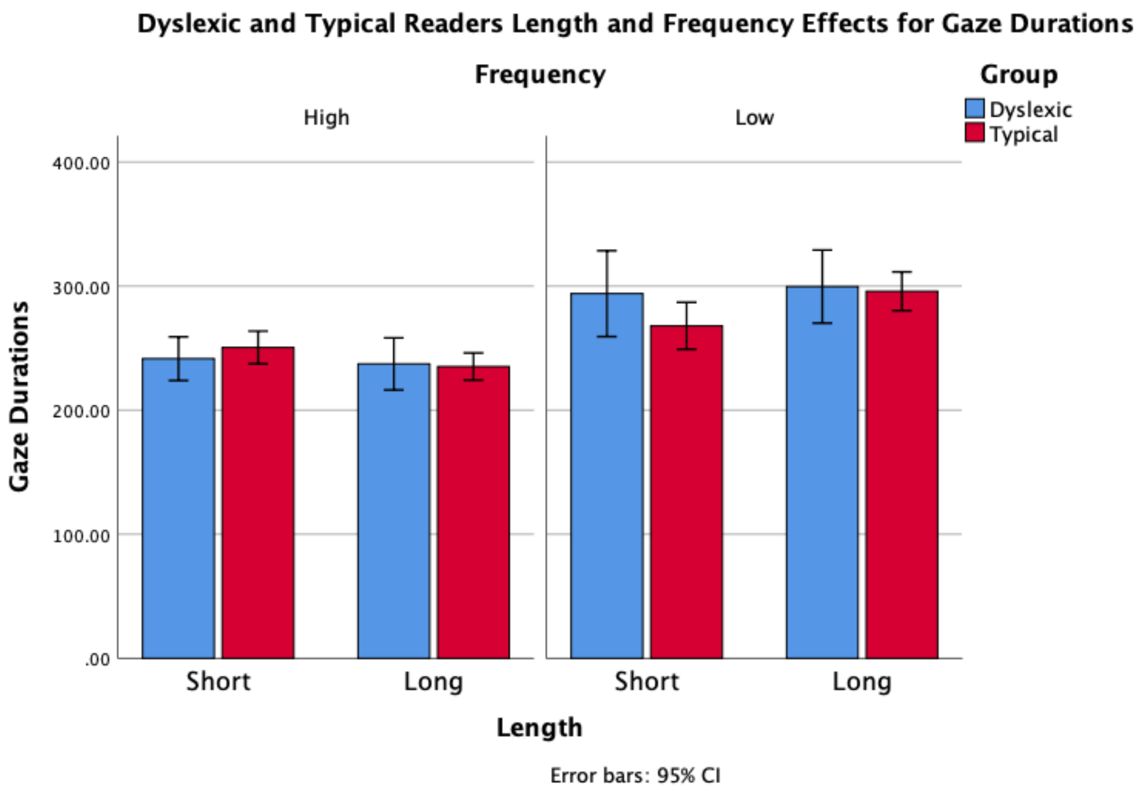

Figure 26. Length and Frequency Effects for Gaze Durations between Monolingual English Readers with and without Dyslexia

Go-Past Times A main effect of group was found for go-past times *F*(1,252) = 8.67, *p* < .01 such that readers with dyslexia had significantly shorter go-past times (*M* = 235.40, *SD* = 57.99) than readers without dyslexia (*M* = 243.99, *SD* = 75.78).

There was a main effect of frequency *F*(1,252) = 8.57, *p* < .01 for go-past times, high-frequency words had significantly faster go-past times (*M* = 223.17, *SD* = 54.91) than low-frequency words (*M* = 262.50, *SD* = 84.64).

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There was a main effect of length $F(1,252) = 18.75$, $p < .001$ for go-past times, such that short words had significantly faster go-past times ($M = 224.48$, $SD = 70.31$) than long words ($M = 260.01$, $SD = 72.83$).

There was a significant length x frequency interaction for go-past times, $F(1,252) = 11.58$, $p < .01$, as demonstrated in Figure 27, indicating that there was no length effect for high-frequency words, but there was a length effect for low-frequency words. As seen in Figure 27, High-frequency short words did not have significantly faster go-past times than high-frequency long words ($M_{short} = 220.59$, $SD_{short} = 64.18$;. $M_{short} = 225.76$, $SD_{short} = 44.10$), however, low-frequency short words did have significantly faster go-past times than low-frequency long words ($M_{long} = 228.63$, $SD_{long} = 76.65$; $M_{long} = 294.26$, $SD_{long} = 79.79$).

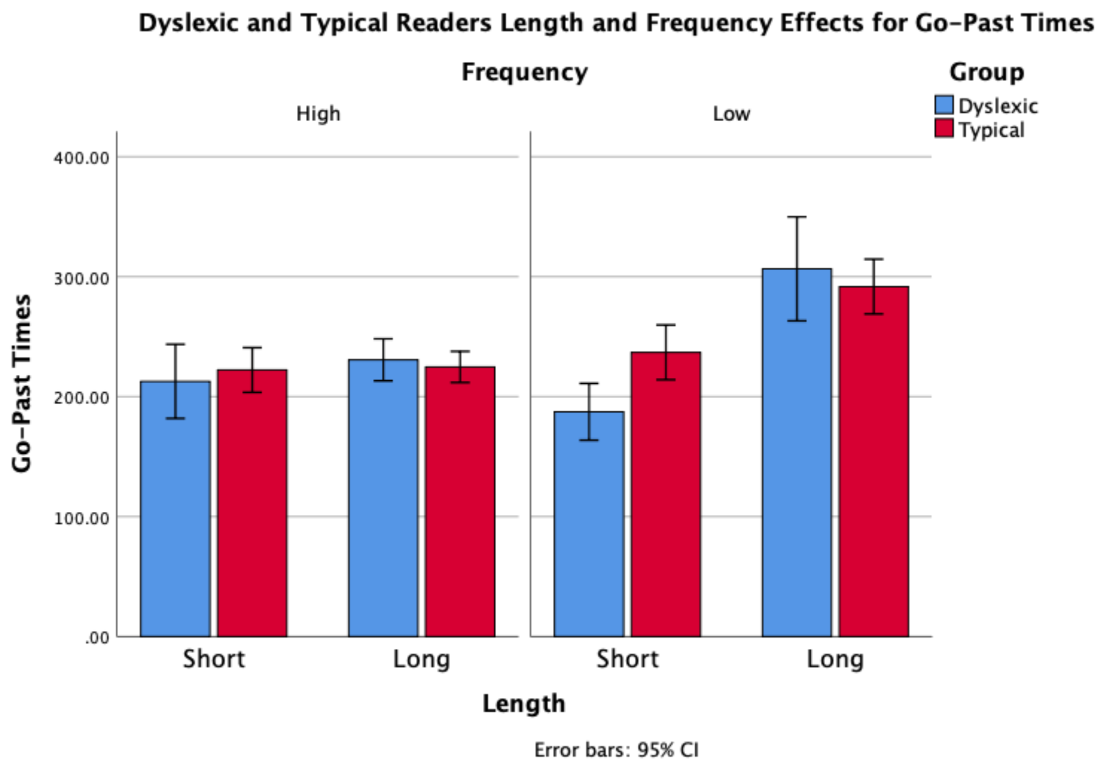

Figure 27. Length and Frequency Effects for Go-Past Times between Monolingual English Readers with and without Dyslexia

Reading Behaviour Between a Consistent and an Inconsistent Orthography

Total Reading Times A main effect of group was found for total reading times $F(1,252) = 8.38$, $p < .01$. As seen in Figure 28, readers with dyslexia had longer total reading times ($M = 500.23$, $SD = 127.91$) than readers without dyslexia ($M = 453.14$, $SD = 143.86$).

There was also a main effect of frequency for total reading times $F(1,252) = 9.10$, $p < .01$ such that high-frequency words were read faster ($M = 369.25$, $SD = 129.02$) than low-frequency words ($M = 437.88$, $SD = 141.65$).

There was a main effect of length for total reading times $F(1,252) = 33.69$, $p < .001$ such that short words were read faster ($M = 347.02$, $SD = 115.49$) than long words ($M = 457.27$, $SD = 139.52$).

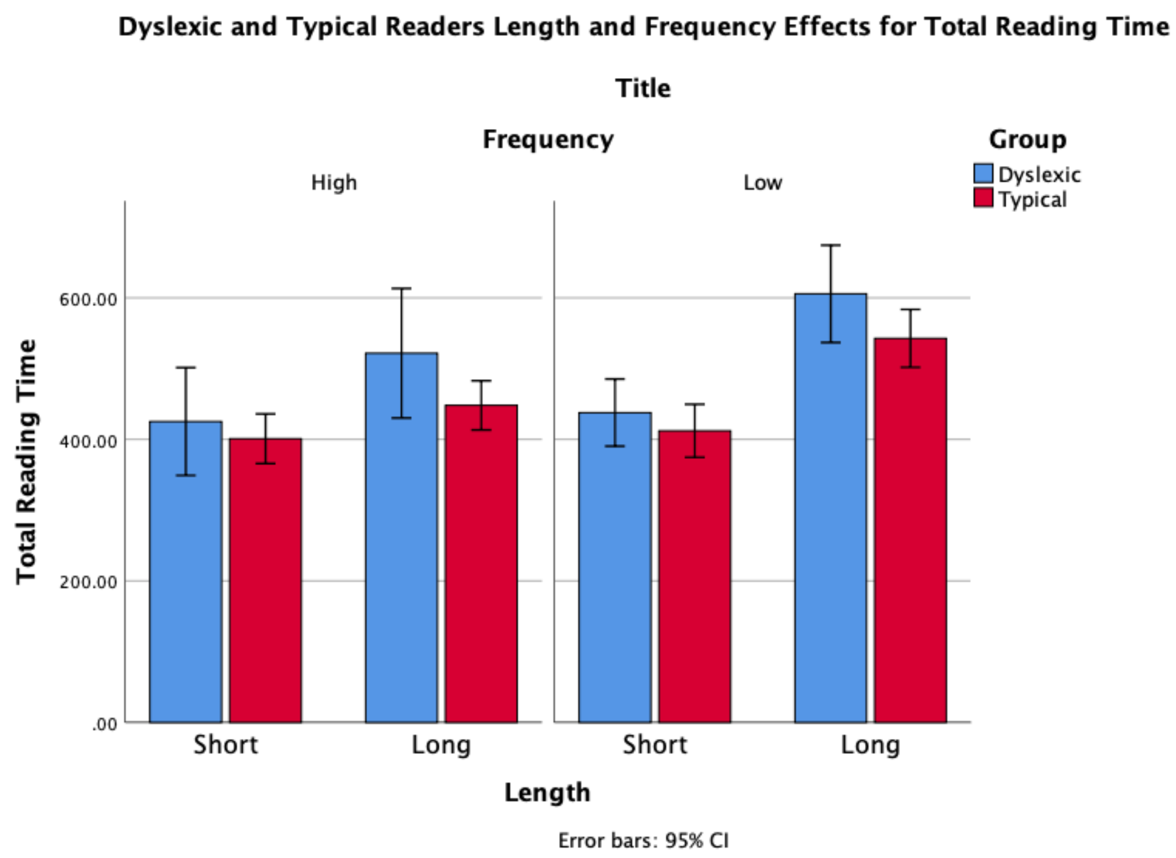

Figure 28. Length and Frequency Effects for Total Reading Time between Monolingual English Readers with and without Dyslexia

3.3.4.5 Correlations Between Eye Movement Patterns and Behavioural Measures for English Readers with Dyslexia

To test whether the scores from the WMLS III were related to eye movement patterns, a series of correlations between each eye movement measure and each language ability measure from the WMLS III have been conducted. Only significant correlations were reported.

Sentence-Level Measures for English Readers with Dyslexia

First, we correlated the WMLS III scores with the whole sentence eye movement scores (average fixation duration, total fixation count, regression count and total reading time) with Bonferroni corrected alphas of .013. No significant correlations were found between any of the sentence-level eye movement measures and the WMLS III measures.

Word-Level Measures for English Readers with Dyslexia

Next, the WMLS III scores and eye movements measured at the word-level (first fixation duration, gaze duration, go-past time, and total reading time) were correlated with Bonferroni corrected alphas of .003.

Only one significant negative correlation was found between vocabulary scores and go-past times for high-frequency long words $r(15) = -.71$, $p < .01$. These results indicate that as vocabulary scores increased, go-past times for high-frequency long words decreased.

3.3.5 Discussion

The goal of *Experiment 4* was to test reading strategies of readers with dyslexia as measured by eye movements and to compare these with age-matched typically developing readers and with the patterns of reading abilities as described in the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990). Eye movement patterns offer both temporal and spatial information beyond what can be obtained via offline reading assessments and thus are an informative way of measuring lexical access.

Reading Behaviour Between a Consistent and an Inconsistent Orthography

As predicted, (Hypothesis-1), sentence-level eye movement patterns differed significantly between readers with dyslexia and typically developing readers. Specifically, findings demonstrated that readers with dyslexia exhibited more regressions and fixations than typically developing readers and spent more time reading sentences. However, fixation durations were not significantly longer for readers with dyslexia.

It was also expected (Hypothesis-1) that both early and late eye movements would be slower for readers with dyslexia compared to typically developing readers. This hypothesis was partially supported. Early eye movement measures exhibited by readers with dyslexia did not differ significantly from age-matched typically developing readers. However, findings suggested that typically developing readers demonstrated faster total reading time eye movement measures than readers with dyslexia. Interestingly however, readers with dyslexia had significantly shorter go-past times.

As expected, (Hypothesis-2*)*, early eye movement measures were found to be affected by word frequency while late eye movement measures were influenced by word length. It was also predicted that these effects would be larger for readers with dyslexia, than the typically developing age-matched readers. Although it was not significant, mean eye movement measures suggested that these effects were larger for readers with dyslexia than the age-matched typically developing readers. Interestingly, although it was not a significant effect, compared to typically developing readers, readers with dyslexia demonstrated shorter early measures of reading when reading high-frequency words. Readers with dyslexia also demonstrated relatively shorter first fixation durations and go-past times when reading short words compared to typically developing readers.

The component skills from the SVR, and also vocabulary knowledge were not found to correlate with sentence-level eye movement measures but vocabulary did significantly correlate with several word-level eye movement measures (Hypothesis-3). Each of these findings will be discussed in further detail below.

3.3.5.1 Eye Movement Strategies of native-English Readers with Dyslexia

Sentence-Level Measures for English Readers with Dyslexia

The results from sentence-level analyses indicated that the current sample of readers with dyslexia exhibited more regressions and fixations than typically developing readers and spent more time reading sentences. These findings support the first hypothesis and are also consistent with previous findings from the literature that readers with dyslexia tend to exhibit more frequent fixations and regressions and spend longer time reading than typically developing readers (e.g., Pavlidis, 1985; Rayner, 1998; Tinker, 1965).

Unexpectedly however, fixation durations were not significantly longer for readers with dyslexia, and in fact, were shorter than the readers without dyslexia. These findings differ from previous studies that have reported longer fixation durations for dyslexic children compared to typically developing readers (e.g., Pavlidis, 1985; Rayner, 1998; Rubino & Minden, 1973; Tinker, 1965). Thus, it is not immediately clear why readers with dyslexia would make shorter fixation durations than readers without dyslexia. However, the current sample of adult readers may differ from the participants from previous studies based on reading experience. Presumably, reading experience may change eye movement patterns for older readers why may have developed strategies to combat phonological deficits including shorter, but more frequent fixations to efficiently processes sentence. This contention is further validated by the finding from *Experiment 3* that vocabulary, language comprehension, and reading comprehension were not significantly poorer, and in fact in some cases, were even better for readers of dyslexia compared to readers without dyslexia. If this is the case, and eye movements change over development in readers with dyslexia to compensate for poor phonological ability, this suggests that differences in eye movements between readers with and without dyslexia are not a consequence of a visual problem, but rather they are reflecting the use of cognitive reading strategies. Further research is needed to validate these conclusions.

Word-Level Measures for English Readers with Dyslexia

The word-level measures were analysed in terms of length and frequency effects. These effects were also compared to the eye movement patterns of the age-matched typically developing readers who had been measured in *Experiment 2*.

Based on reported findings that dyslexic readers are generally slower with more fixations and regressions (e.g., Pavlidis, 1985; Rayner, 1998; Tinker, 1965), it was expected that both early and late eye movement measures would be slower for readers with dyslexia than for typically developing readers, however this has never been directly investigated. The current experiment predicted that eye movement patterns for a sample of readers with dyslexia would be sensitive to both length and frequency effects; however, it was expected that the time-course of these effects would differ. Specifically, it was expected that frequency effects would be most sensitive in early measures of lexical access (first fixation durations and gaze durations), while length effects would be most sensitive in late eye movement measures (go-past times and total reading times).

As previously discussed, there is a robust finding across the literature that low-frequency words are less likely to be skipped and are fixated upon longer than high-frequency words (Altarriba et al., 1996; Hyönä & Olson 1995; Inhoff & Rayner 1986; Just & Carpenter 1980; Rayner & Duffy 1986; Rayner & Raney 1996; Rayner et al., 1996; 1998; Vitu et al., 2001), indicating that low-frequency words are processed more slowly and effortfully than high-frequency words in English readers. In the current experiment, both length and frequency effects were found for readers with dyslexia, however the time-course of these effects differed.

As expected, (Hypothesis-2), early eye movement measures were found to be affected by word frequency while late eye movement measures were influenced by word length. However, a significant frequency x length interaction indicated that length effects were only found for low-frequency words for go-past times. These findings differ from the typically developing readers in *Experiment 2*, who demonstrated a frequency effect for all eye movement measures, but only length effects for low-frequency words in late eye movement measures. However, these findings are consistent with those reported by Provazza et al. (2019) who found both length and frequency effects for adult native-English readers with dyslexia. The results from the current experiment suggest that for the current sample of adult readers with dyslexia, words that are lower in frequency may require additional early lexical processing time since such words are less familiar to readers than high-frequency words. When a low-frequency word is encountered, and early lexical processes fail to find an adequate word match in the lexicon, dyslexic readers will apply the sub-lexical procedure to process the low-frequency word. Reading processes for low-frequency words in turn are affected by length and thus may affect the later eye movement measures. The finding that readers with dyslexia only showed frequency effects in early eye movement measures may support the notion that they are over-relying on the sub-lexical route to read words. If they are not employing the lexical procedure as often as typically developing readers, then perhaps their late-stage eye movement measures would not be affected by a word's frequency, only length.

Similar findings have been reported in research that has investigated the differences between adults (skilled readers) and children (less skilled readers). Pagán, Blythe and Liversedge (2021) have reported that first fixation durations and gaze durations are sensitive to misspelled words for both children and adults. Interestingly, adults were found to be most sensitive to words that had misspellings at the beginning compared to the middle or the end of each word, while children were sensitive to misspelled words no matter where the misspelling occurred. These results may also suggest evidence that the more skilled adult readers are able to process larger grains of information at a time (i.e., morphemes or whole words) instead of relying on letter-by-letter decoding as children may still need to do, thus supporting the Psycholinguistic Grain Size Hypothesis (Ziegler & Goswami, 2005).

Thus, if readers with dyslexia are relying on a sub-lexical decoding strategy regardless of frequency, it would be expected that the eye movement measures associated with this strategy would be affected. However, once the early eye movement measures process the frequency status of a word, late eye movements may remain unaffected. On the other hand, length may not necessarily affect eye movement patterns associated with decoding and phonological integration but will affect late eye movements which reflect total processing time as well as semantic integration and ambiguity resolution. These predictions stemmed from evidence that readers with dyslexia may demonstrate inefficient lexical procedures paired with an over-reliance on sub-lexical decoding strategies (Hawelka et al., 2010).

The observation of frequency effects in early measures of reading is consistent with results from previous literature from typically developing readers (e.g., Ashby, Rayner & Clifton, 2005; Blythe et al., 2009; Inhoff and Rayner 1986; Rau, Moll, Snowling & Landerl, 2015). Early eye movement measures that reflect early lexical access may be sensitive to frequency effects since low-frequency words may slow the sub-lexical route once the lexical route fails to find a reliable match in the lexicon. However since the sub-lexical route is notoriously unreliable in English, this may have affected the early eye movement measures associated with phonological processing and decoding. An increased reliance on these early measures may have been sufficient for the current sample of readers with dyslexia to resolve the discrepancy and later measures of lexical access may have been able to perform normally.

These findings from the current experiment are also consistent with some findings from Hyona and Olson (1995) who also found frequency effects but not length effects for first fixation durations in readers with dyslexia. However, the results from the current experiment differ slightly from those reported by Hyona and Olson such that they report both length and frequency effects for gaze durations, and second-pass reading times while the current experiment only found frequency effects for gaze durations and only length effects for go-past times (similar to second-pass reading times). It is possible that the results from the current experiment differ from those reported by Hyona and Olson for several different reasons. First, the sample in the current experiment are adults with dyslexia who may have developed compensatory reading strategies over time to compensate for poor decoding skills. This may result in different types of eye movement strategies as well. Second, as previously discussed, the participants in Hyona and Olson's study were asked to read material that was above their reading level. Thus, the eye movements may not have been sensitive to the phonological impairments of the dyslexic readers.

It was also expected that length and frequency effect would be larger (i.e., the size of the difference between the faster time and the slower time) for readers with dyslexia compared to age-typically developing readers. However, group x frequency, and group x length interactions indicated that these effects were not significantly larger for readers with dyslexia compared to typically developing readers. Although it was not significant, mean eye movement measures suggested that these effects were larger for readers with dyslexia than the age-matched typically developing readers. Evidence has been reported previously that length and frequency effects may be larger for readers with dyslexia compared to typically developing readers when accuracy or reaction time are the dependent measures (e.g., Hyona & Olson, 1995, Provazza Giorfe, Adams & Roberts, 2019; Richlan et al., 2010; Ziegler et al., 2003; Zoccolotti et al., 2005). However, in the case of eye movements, Hyona and Olson (1995) reported that larger length and frequency effects were only found for second-pass reading times. While the results from the current experiment did not find this pattern, it is possible that a larger sample size of readers with dyslexia may have elicited a significant effect. However, the sample in the current experiment consisted of adult readers with dyslexia while Hyona and Olson's participants were children. Therefore, it is equally possible that adult readers with dyslexia may have developed compensatory reading strategies resulting in more efficient eye movement patterns. This interpretation is consistent with the idea that some readers with dyslexia my become 'resilient readers' and learn to compensate for poor decoding by developing strategies that allow them to rely more on semantic processes and contextual clues to support the reading process (e.g., Bishop and Snowling, 2004; Elbro & Arnbak, 1996; Jackson & Doellinger, 2002; Que´mart & Casalis, 2015; Snowling, 2000).

Interestingly, although it was not a significant effect, compared to typically developing readers, readers with dyslexia demonstrated overall shorter early measures of reading when reading high-frequency words. Readers with dyslexia also demonstrated relatively shorter first fixation durations and go-past times when reading short words compared to typically developing readers. These findings may provide additional support to the notion that readers with dyslexia show an over-reliance on the sub-lexical route rather than the lexical one. Eye movements that reflect initial lexical access may be shorter for readers with dyslexia in order to devote more resources to late stage reading processes which are reflected by go-past times and total reading times.

More broadly, these findings also appear to support phonological deficit theories (Bradley and Bryant, 1978; Brady and Shankweiler, 1991; Snowling, 1981; Vellutino, 1979) rather than visual theories of dyslexia (Livingstone et al., 1991; Lovegrove et al., 1980; Stein and Walsh, 1997). Since frequency is purely a linguistic characteristic rather than a visual one, the finding that eye movements for dyslexic readers were sensitive to frequency effects suggests that eye movements may reflect, rather than a cause of problems with reading. This conclusion also supports models of eye movement control during reading such as the E-Z Reader (Pollatsek, Reichle, & Rayner, 2006; Reichle, Rayner, & Pollatsek, 1999, 2003) and SWIFT (Engbert, Nuthmann, Richter, & Kliegl, 2005; Kliegl & Engbert, 2003) model which purport that linguistic processes directly affect eye movement patterns.

3.3.5.2 Correlations between Eye Movements measures from Readers with Dyslexia and the Simple View of Reading Component Skills

To investigate whether eye movement strategies might be related to the component skills i.e., decoding, language comprehension, and reading comprehension, described in the SVR (Gough & Tunmer, 1986), these eye movement measures were correlated with the abilities measured in *Experiment 3*. The SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990) posits that a reader's decoding skills (D) and language comprehension abilities (LC) are strong predictors of Reading Comprehension (RC).

Similar to the age-matched typically developing readers (*Experiment 2),* for a sample of adult readers with dyslexia, it was expected (i.e., Hypothesis-4), that decoding skills would correlate with early eye movement measures of lexical access (e.g., first fixation duration and gaze durations) as well as fixation duration, fixation and saccade count since research has shown these eye movements may reflect phonological processes (Kuperman & Van Dyke, 2011; Liversedge, Paterson, & Pickering, 1998; Rayner, Chace, Slattery & Ashby, 2006; Rayner, 1998; Rayner, 2009). In contrast, it was expected that language comprehension and reading comprehension would correlate with the late eye movement measures of lexical access (e.g., go-past times and total reading times) as well as sentence-level measures of total reading times since these eye movements may reflect higher order processing (Kuperman & Van Dyke, 2011; Liversedge, Paterson, & Pickering, 1998; Rayner, Chace, Slattery & Ashby, 2006; Rayner, 1998; Rayner, 2009). Since vocabulary knowledge was the strongest predictor of reading comprehension in the current sample of dyslexic readers, and since it is an important factor in building the lexicon, it was also expected that this skill should correlate with eye movement measures specifically for low-frequency words.

Sentence-Level Measures for English Readers with Dyslexia

Unexpectedly, none of the sentence level eye movement measures significantly correlated with any of the component skills from the SVR measured in *Experiment 3*. This is surprising given that decoding is assumed to be reflected by eye movement measures such as total fixation count, and forward saccade count, which are both indicators of sub-lexical strategies according to previous research (Rayner, 1998, Rayner, 2009; Liversedge, Paterson, &

Pickering, 1998, Korneev, Matveevn, & Akhutina, 2020). Further, results from *Experiment 2* with the typically developing age-matched readers demonstrated that decoding scores were negatively correlated with total average fixation counts. However, these findings were not replicated in the current study with readers with dyslexia.

The findings that decoding did not significantly correlate with any of the sentence-level eye movement measures for dyslexic readers may not be surprising considering that this skill was not a good predictor of reading comprehension for the current sample. Further, decoding did not significantly correlate with other skills such as language comprehension. Given these findings, decoding skills may not be a good indicator of reading abilities for adult readers with dyslexia and thus eye movements employed during reading may not reflect these skills.

It is not immediately clear why language comprehension, reading comprehension, and vocabulary did not significantly correlate with any of these eye movement measures for readers with dyslexia. One possibility is that the reading material was too simple in the current experiment to elicit strong correlations with reading skills. In *Experiment 2*, the age-matched typically developing readers also showed no correlations between vocabulary or language comprehension and these sentence-level eye movement measures. Perhaps text that is more challenging to read would elicit different results. Further research using different texts is needed to clarify these results.

Word-Level Measures for English Readers with Dyslexia

While none of the sentence-level eye movement measures significantly correlated with any of the SVR component skills in the current sample of readers with dyslexia, some of the word-level measures did. Again, decoding did not significantly correlate with any of the eye movement measures. This may not be surprising considering that decoding skills were not good predictors of reading comprehension in the current sample of readers with dyslexia. Higher vocabulary scores were associated with faster go-past times for high-frequency long words. These findings indicate that better vocabulary for dyslexic readers may particularly support higher-frequency words for longer letter-strings.

Taken together these results may indicate that these eye movement measures do not reflect well the component skills from the SVR nor vocabulary for the current sample of readers with dyslexia. These findings differ from those reported in *Experiment 2* with the age-matched typically developing readers. In *Experiment 2*, there were significant negative correlations between decoding scores and early measures of reading (i.e., gaze duration) for all low-frequency words indicating that as decoding scores increased, gaze durations were shorter low-frequency words. It is surprising however that these eye movement measures were only correlated with vocabulary knowledge. One reason for this may be that since readers with dyslexia may be particularly poor at processing letter-strings and particularly low-frequency words, their eye movement patterns employed on these types of words are not accurate reflections of the reading skills used to process these words. However, it is equally possible that perhaps eye movements of dyslexic readers do stem from some visual deficit rather than reflecting poor reading skills as some have suggested (e.g., Biscaldi, Fischer, & Aiple, 1994; Eden, Stein, Wood, & Wood, 1994; Goldrich & Sedgwick, 1982; Griffin et al., 1974; Hildreth, 1963; Lesevre, 1964; 1968; Pavlidis, 1981, 1983; Zangwill & Blackemore, 1972). However, given that these eye movement measures were sensitive to word frequency, this possibility is unlikely. Another possibility is that these eye movement measures are reflecting some other skill that was not measured in the current Chapter. These results are difficult to interpret given that no other study has investigated the associations between the SVR components and vocabulary and these eye movement measures. Further research that measures a wider variety of skills in samples with similar characteristics is needed to gain a better understanding of these findings.

3.3.5.3 Limitations and Further Research

One major strength of this experiment is that it examined the time-course of length and frequency effects during reading and compared both online and offline measures of reading.

Results indicate however, that the eye movement measures observed in the current sample may have reflected abilities that were not measured in offline tasks, and thus these abilities are unknown. Future research would benefit from including a battery of offline tasks to measure a wider variety of reading abilities and not just the ones indicated in the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990). Further, since decoding skills did not significantly correlate with any eye movement measures, it is also possible that none of the eye movements measures in the current experiment actually reflect decoding skills of readers with dyslexia. This could result due to the readers only being exposed to simple sentences which may have been too easy for participants. Future research should include a variety of easy and complex sentences to explore this possibility.

Additionally, the results that analysed the measures of reading comprehension, may be difficult to interpret based on the nature of the way reading comprehension was measured in the current experiment. In *Experiment 2*, reading comprehension was measured using a cloze task where participants were instructed to provide missing words from texts of increasing difficulty. A cloze reading may have been more cognitively taxing than the task participants completed in the current eye-tracking experiment where they read short simple sentences for meaning and answered a subsequent comprehension question. Thus, the reading results in the cloze task may be difficult to compare to the results from the eye-tracking. Future research would benefit from using several measures of reading comprehension and compare each of them with eye movement measures.

3.3.5.4 Conclusion

The present experiment aimed to explore reading strategies as measured by eye movements in adult readers with dyslexia while they read whole sentences for meaning embedded with target words that were controlled for length and frequency. These findings were compared to those measured in age-matched typically developing readers from *Experiment 2*. Further, the current experiment also compared eye movement measures of reading with the measured reading abilities of the components described in the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990). Frequency effects were found mostly for early eye movement measures of reading, while length effects were found for late eye movement measures of reading. Thus, there was a differential time-course of word-level effects where word frequency affected early lexical access and word-length affected later lexical access. These results accord with the DRC (e.g., Coltheart et al., 2001) and lend support to phonological deficits as a predominant cause of dyslexia rather than a visual deficit.

Decoding skills did not significantly correlate with many eye movement measures in the current sample, however language comprehension, vocabulary skills, and reading comprehension did correlate with several of the early measures of eye movements for high-frequency words. Further research is needed to better understand and interpret these findings.

Chapter 4: The Simple View of Reading in a Consistent Language, Spanish: A Behavioural Experiment and an Eye Movement Experiment

4.1 Chapter 4 Overview

Experiments 1- 4 (in Chapters 2 and 3) demonstrated reading strategies of monolingual readers of English, an inconsistent orthography with and without dyslexia. The current Chapter investigated the reading strategies of age-matched native readers of Spanish, a consistent orthography while they read sentences for meaning in their native consistent orthography.

This Chapter consists of two Studies with two Experiments: *Experiment 5* a behavioural study where Spanish-English bilingual participants' language skills such as language comprehension, vocabulary knowledge, decoding skills and reading comprehension were evaluated in Spanish, and *Experiment 6* an eye-tracking experiment where participants read sentences in Spanish while their eye movements were recorded.

4.2 Experiment 5: The Simple View of Reading in a Consistent Orthography, Spanish

4.2.1. Introduction to the Spanish Orthography

Spanish, an Indo-European romance language derived from Latin, is the world's second most spoken native language (Instituto de Cervantes, 2014). Spanish is the common language of Spain, and the main language in many Central and South American countries. Spanish is the national language for twenty-one countries and is of growing importance in the United States (Defior & Serrano, 2017).

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Spanish is an alphabetic orthography where the smallest unit of sound lies at the phoneme level. Unlike English however, Spanish has been widely standardized and linguistic rules are governed by the Royal Spanish Academy (Real Academia Española). As a result, Spanish has a phonetically transparent orthography with a consistent grapheme-phoneme correspondence with few exceptions (GPCs; Perfetti & Dunlap, 2008; Ramirez, Chen, Geva, & Kiefer, 2010; Defior & Serrano, 2017). Spanish consists of 27 letters, the same as English but with the addition of the *eñe* (ñ), and 24 phonemes (for a review, see Alacros Llorach, 2007). Thus, there is a high level of predictability in reading the Spanish orthography. However, the grapheme-phoneme conversion is not entirely consistent and there are a few exceptions. For example, the letter "c" is pronounced /s/ if it is in front of an "e" or an "i", but is pronounced like /k/ in other instances. There are a total of eight consonant phonemes that can be represented using more than one grapheme: /b/ (B, V, W), /k/ (K, QU, C), /g/ (G, GU), /x/ (G, J), /j/ (Y, LL), /rr/ (R, RR), /Ø/(Z, C), /s/ (S, X) (see Soriano-Ferrer & Morte-Soriano, 2017). It is important to note that these exceptions affect the transparency of *written* Spanish, but do not affect the transparency of *reading*. Hence, Spanish will be easy and predictable to read, but less predictable to write (Defior & Serrano, 2017). Thus, Spanish, is considered to have a consistent orthography in which there is close to a one-to-one correspondence between graphemes and phonemes used to represent them.

Spanish also has a different morphological system to English. Though it is outside the scope of the current thesis to discuss all these differences, some aspects that affect meaning while maintaining phonology of words are worth noting as they affect reading comprehension (though for a review, see Alacros & Llorach, 2007). For one, Spanish has a more complex morphological system and is considered a highly inflected language. Spanish has up to 47 inflectional suffixes which are used to indicate changes in grammar or meaning (Ramirez et al., 2010); (e.g., *si* [if] vs. *sí* [yes]). It is important to note that such inflections affect the semantic characteristics of words, but do not affect phonology. In English, and in most inconsistent languages morphology or spelling, tends to be preserved at the expense of phonology (Perfetti & Harris, 2017). For example, English words such as “heal” and “health” keep the stem morpheme even though the pronunciation is different (Bryant & Nunes, 2004). In contrast, Spanish tends to sacrifice morphology in favour of maintaining phonology (Defior & Alegría, 2005). For example, the letter “c” in the root word *vaca* (cow) changes to “qu" to keep the same sound in derived words like *vaquero* (cowboy) or *vaquería* (dairy farm). This tendency keeps the transparency of the orthography intact. In English and in other inconsistent orthographies that prioritise morphology over phonology, acquisition of morphological awareness is necessary to learn GPCs (e.g., Carlisle, 2000; Rastle, 2018; Singson, Mahony & Mann, 2000). Although morphological awareness has been shown to be an advantage in consistent orthographies, it is not a necessary skill because phonology is represented well enough to facilitate rapid pronunciation (Álvarez, Carreiras, & Taft, 2001; Ziegler & Goswami, 2005).

Overall, there are some key differences between the Spanish and English orthography. Consequences for reading development because of these differences will be discussed in the following sections.

4.2.1.2 From Development to Skilled Reading in Spanish

Similar to English, learning to read in Spanish is also contingent on learning GPCs. Although some processes of reading development in Spanish are similar to those in English, there are some key differences that may stem from the consistency of the Spanish orthography. This section will briefly review word reading development in Spanish and will highlight the similarities and differences in reading development compared to readers of English.

The basics of reading and phonological decoding are acquired quickly for Spanish children, and the alphabetic code is usually mastered by the end of their second year of primary school (ages 7-8) (for a review see Defior & Serrano, 2017). Spanish readers reach ceiling accuracy in decoding by the beginning of Grade-2, around age 7, however speed is characterized by a more gradual improvement (Defior et al. 2011). As discussed in Chapter-

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1 children reading in a consistent orthography tend to acquire phonological skills quickly and are generally faster and more accurate at reading both words and nonwords earlier compared to readers of an inconsistent language (Goswami, 2010; Seymour, Aro & Erskine, 2003). On the other hand, reading development in English is characterized by a slow development in accuracy in both regular and non-regular words (e.g., Coltheart & Leahy, 1996). For example, Zeigler and Goswami (2005) sampled studies of kindergarteners and Grade-1 readers from five different orthographies (i.e., Turkish, Greek, Italian, French, and English) and found that the readers from the consistent orthographies such as (Turkish, Italian, and Greek) were able to count more phonemes and syllables at both grade levels than the readers of French and English. Such results between consistent and inconsistent orthographies are generally interpreted to indicate that readers of consistent orthographies can consistently rely on sub-lexical strategies to efficiently read most words. Spanish is no different from other consistent orthographies in this case.

Though the sub-lexical procedure is relatively efficient for reading, skilled readers of Spanish may also utilize the lexical procedure for reading. For example, young readers of Spanish have been shown to be more sensitive to length effects in reading than adults. Acha and Perea (2008) compared length effects and transposed-letter effects (i.e., words formed by the transposition of two letters: e.g., aminal–ANIMAL, or by the substitution of two letters: e.g., arisal–ANIMAL, in young readers of Spanish aged 7 with skilled adult readers aged 22. The younger readers showed a large length effect (i.e., longer words were read slower than shorter words) and transposed-letter effect (i.e., responses were slower when presented with a transposed-letter word compared to a letter-substitution word) which was absent in adult readers. This was interpreted to show that skilled readers of Spanish may read via direct lexical access while younger readers use a sub-lexical procedure.

Reading acquisition in Spanish thus seems to be foundational upon some of the same core underlying skills such as phoneme awareness, that are important for reading in other alphabetic orthographies such as English. However, some differences that stem from orthographic consistency are apparent. Specifically, decoding skills tend to develop quickly and early for readers of Spanish because the orthography is consistent, and reading is easily predictable compared to reading an inconsistent orthography such as English. Based on these findings, it is reasonable to assume that decoding skills may demonstrate a distinct relationship with reading comprehension for Spanish readers compared to readers of English which may in turn affect the relationship of language comprehension to reading comprehension. The next section will review how orthographic consistency may impact reading comprehension across alphabetic languages within the context of a well-supported model of reading, The SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990). As previously discussed, the SVR has been well supported in readers of English (e.g., Hoover & Gough, 1990; Sabatini et al., 2010; MacArthur et al., 2010; Vellutino et al., 2007; Barnes & Kim, 2016; Goswami, 2002), however it is also useful to test this model in different languages with more consistent orthographies to further understand the influence of orthographic consistency on reading.

4.2.2 The Simple View of Reading in a Consistent Orthography

Though one of the initial studies used to support the SVR was carried out using Spanish-English bilingual children (i.e., Hoover & Gough, 1990), most evidence reported to support the SVR since has been heavily based on reading in English (e.g., Oakhill et al., 2003; Tilstra et al., 2009; Kendeou, Savage, & van den Broek, 2009). However, since readers of different orthographies have been found to approach text differently, and that decoding skills may develop differently, it would be reasonable to expect that the relative pattern of contributions to reading comprehension from the component skills (decoding and language comprehension) described in the SVR may also be different for different orthographies.

4.2.2.1 The Nature of Decoding and Language Comprehension Skills in a Consistent Orthography

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As previously discussed in Chapter-1, decoding is acquired quickly in early development for readers of a consistent language compared to readers of an inconsistent orthography (Goswami, 2002; Seymour, Aro, & Erskine, 2003, Hoover & Gough, 1990). Decoding skills contribute to a large amount of variance for beginning readers of English, however this contribution tends to gradually decrease with development, while the contribution of language comprehension increases with development (Hoover & Gough, 1990). In contrast, the relative contributions of decoding and language comprehension to reading comprehension may be distinct for readers of a consistent orthography compared to readers of inconsistent orthographies. For example, Seymour and colleagues (2003) measured decoding skills including grapheme-phoneme knowledge, familiar word identification and nonword reading in readers from fourteen languages varying in orthographic consistency. Results demonstrated that familiar word identification and nonword reading were affected by orthographic depth such that readers of English and other inconsistent languages (e.g., French, Portuguese and Danish) were slower and less accurate at these skills than readers of consistent languages (e.g., Italian, Spanish, Finnish, and Greek). Grapheme-phoneme knowledge did not differ across languages, likely because word decoding skills may be affected by orthography, explicit phonemic awareness of letters may still develop at similar rates across languages (Duncan, Seymour & Hill, 1997).

Research has demonstrated that readers of consistent orthographies master decoding accuracy early on in reading. For example, Spanish readers reach ceiling accuracy in decoding by the beginning of Grade-2, around age 7 (Defior et al., 2011). Readers of an inconsistent orthography, however, may not master decoding ever, but gain proficiency with it. Thus, under the assumptions of the SVR (Gough& Tunmer, 1986; Hoover & Gough, 1990), decoding would account for some of the variance in reading comprehension until it is mastered, at which point, the rate of reading comprehension would increase as the rate of language comprehension increases. However, once decoding is proficient, language comprehension accounts for more of the variance in reading comprehension. A recent study conducted by Lonigan and Burgess (2017) on English children found that reading comprehension skills could not be distinguished separately from decoding skills until Grade-3 (aged 9). Considering the hypothesized multiplicative relationship of the components of the SVR, (RC = D x LC), the SVR would define mastery of decoding as a perfect score (decoding = 1) which remains constant (1 x language comprehension (0-1) = reading comprehension). Thus, all variation in reading comprehension scores would be based only on the language comprehension component scores in the case where decoding skills are mastered.

Indeed, studies examining the SVR in consistent orthographies such as Spanish (Pallante & Kim, 2013), Dutch (de Jong & van der Leij, 2002), Norwegian (Hagtvet, 2003) and Greek (Protopapas, Sideridis, Mouzaki, & Simos, 2007), where decoding ability is quickly acquired, have all found that language comprehension begins to become a better predictor of reading comprehension than decoding much earlier than for readers of English. In a large-scale meta-analysis, Florit and Cain (2011) examined the validity of the SVR in 20 studies carried out with English-speaking children, and 13 with children speaking other European languages including Greek, Dutch, Norwegian, Spanish, Italian, Finnish, French, and German. The articles chosen for the meta-analysis included samples of children ranging from preschool at age 4-5 to Grade-4 age 10 to 11. Results revealed that the relative influence of decoding and language comprehension on reading comprehension does indeed vary across readers of different types of orthographies. Decoding was found to be a more influential predictor of reading comprehension in the early years of reading development for readers of English. Specifically, decoding correlated with reading comprehension at r = .80 in preschool and Grade-1 and still at r = .78 in Grade-2 to Grade-4, while language comprehension only correlated with reading comprehension by r =.38 in years preschool and Grade-1 and by r =.71 in Grade-2 to Grade-4. On the other hand, language comprehension abilities were better predictors of reading comprehension than decoding in early years of reading especially for readers of consistent orthographies (e.g., Italian, Spanish, and Finnish).

Specifically, reading comprehension for the group of readers of transparent orthographies significantly correlated with decoding skills at r =.60 in preschool and Grade-1, and at r = .48 in Grade-2 to Grade-4 while language comprehension correlated with reading comprehension at r = .50, and r =.68 respectively. Thus, for readers of more consistent orthographies, language comprehension can greatly influence variance in reading comprehension even from early stages of reading development.

More recently, Caravolas et al. (2019) investigated the proportion of variance decoding can account for in reading comprehension relative to language comprehension may differ as a function of orthographic depth across the course of development. Predictors of reading comprehension were measured in native-English children, and in children from three consistent orthographies, (i.e., Spanish, Czech, and Slovak) using a longitudinal design. Participants were tested a total of three times: kindergarten, Grade-1, and Grade-2. In kindergarten, participants were tested on letter knowledge, phoneme awareness, RAN, word reading, vocabulary, and language comprehension. Results demonstrated that in all four languages, early skills in word reading, phoneme awareness, and RAN measured in kindergarten predicted decoding skills measured 16 months later at the end of Grade-1. These decoding skills, in turn, predicted reading comprehension measured in the middle of Grade-2 for all languages. However, language comprehension measured in kindergarten were significant predictors of Grade-2 reading comprehension for the consistent orthographies only. These findings indicate that readers of inconsistent orthographies rely heavily on decoding skills in early years, whereas readers of consistent orthographies can begin to develop skills in language comprehension to support reading comprehension because of the ease of decoding in a consistent orthography.

In sum, these findings do not support the SVR which hypothesizes that for increasing levels of decoding skill, there should be a constant intercept value of 0 in a regression formula and positive slope values increasing in magnitude. The percentage of explained variance in reading comprehension for each study was not reported in this meta-analysis, rather the summary effects for the correlations between the decoding, language comprehension, and reading comprehension variables were reported. Thus, an evaluation of the strength of the multiplicative formula across orthographies to account for variance in reading comprehension warrants further investigation. The next section will review research that has examined the SVR formula in readers of consistent orthographies.

4.2.2.2 The Simple View of Reading Formula in a Consistent Orthography

Recall the two inconsistencies that remain across the literature concerning the SVR previously discussed in Chapter-2; (1) whether the multiplicative RC = D x LC or the additive formula RC = D + LC is better at characterising the relationship between decoding, language comprehension and reading comprehension and (2) the proportion of explained variance in reading comprehension.

Results from native English readers with and without dyslexia in *Experiments 1* (Chapter-2) *and 3* (Chapter-3) in the current thesis suggested that both models were adequate in accounting for variance in reading comprehension, however the additive model accounted for slightly more variance. As discussed in Chapter-2, there seems to be a discrepancy in the amount of variance explained by the SVR with some studies reporting a high percentage, (e.g., 65%; Spear-Swerling, 2004; 79%-88%; Catts, Herrera, Nielsen & Bridges, 2015; 71%-89% Hoover & Gough, 1990), while others report that the SVR accounts for less than half the variance in reading comprehension (e.g., 45%-47% Georgiou, Das & Hayward, 2009; 22%-23% Savage & Wolforth, 2007). In the sample of native English readers with and without dyslexia in *Experiments 1 and 3* the SVR accounted for less than half the variance in reading comprehension (45%) for readers without dyslexia but accounted for much more variance in readers with dyslexia (59%). Thus, the predictive validity of the SVR may vary across different readers and thus may vary across readers of different orthographies.

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A few studies have tested the predictions of the SVR in other alphabetic orthographies (e.g., de Jong & van der Leij, 2002; Florit & Cain, 2011; Kendeu, Papadopoulos, & Kotzapoulou, 2013; Müller & Brady, 2001). In general, compared to native readers of English, results from studies on readers from consistent languages suggest that decoding may play a smaller role by Grade-2 or Grade-3 relative to language comprehension skills, in predicting reading comprehension (Portuguese: Cadime et al., 2016; Finnish: Lepola, Lynch, Kiuru, Laakkonen, & Niemi, 2016; Norwegian: Lervåg, Hulme, & Melby-Lervåg, 2017; Italian: Tobia & Bonifacci, 2015). For example, Joshi, and colleagues (2012) measured decoding, language comprehension, and reading comprehension skills in both native-English speaking children and native-Spanish speaking children in Grade-2 and Grade-3. Participants were administered analogous tests of decoding, language comprehension, and reading comprehension. Multiple regression analyses indicated that the SVR could account for 57% of the variance in reading comprehension for Spanish-speaking children in Grade-2, and 60% of the variance for Spanish-speaking children in Grade-3. In the matched English sample, the SVR formula only accounted for 47% and 48% of the variance in reading comprehension for English speaking children in Grades-2 and 3 respectively. Similar to the findings from Florit and Cain (2011), language comprehension exerted a greater influence to reading comprehension than decoding for Spanish-speaking children in Grade-2 and decoding was no longer a significant predictor by Grade-3, while the opposite pattern was found for the English sample in Grade-2, but by Grade-3 decoding and language comprehension exerted equal influence to reading comprehension. Though it will not be discussed in detail, Joshi and colleagues also found that the SVR could account for variances in non-alphabetic languages including 42% or the variance in reading comprehension for readers of Chinese (Joshi et al., 2012) and up to 70% or reading variation in Hebrew-speaking children from Grades-2 to 10 (Joshi et al., 2015).

Though this study is informative, the multiple regression technique represents the additive formula of the SVR. The multiplicative formula was not tested. This is important because the additive and multiplicative formula of the SVR represent different and distinct relationships to reading comprehension. Since *Experiments 1* (Chapter-2) and *3* (Chapter-3) in the current thesis suggested that the additive model of the SVR may be better at accounting for variance in reading comprehension for readers of an inconsistent orthography, it is also important that the multiplicative and the additive formulas of the SVR are tested in a sample of readers of a consistent orthography. For this reason, the current experiment examined skilled readers of a consistent orthography (Spanish) to determine whether they have mastered decoding and whether language comprehension can account for the variance in reading comprehension within the SVR model.

4.2.2.3 The Role of Vocabulary in the Simple View of Reading Formula in a Consistent Language

As discussed previously, vocabulary knowledge has been found to contribute unique variance to reading comprehension in English after decoding and language comprehension skills have been controlled (Binder et al., 2017; Braze et al., 2007; Vellutino et al., 2007; Ouellette & Beers 2010; Tunmer & Chapman, 2012). These findings were reported in *Experiment 1* (Chapter-2) and similar results have been reported for Spanish readers (e.g., Pallante & Kim, 2013). Specifically, Goodwin and colleagues (2015) found that Spanish vocabulary was highly correlated with, and significantly contributed to variance in, reading comprehension (r = .80). Thus, as was done in *Experiment 1* in Chapter-2 and *Experiment 3* in Chapter-3, the current experiment also included a measure of Spanish oral vocabulary knowledge to explore it’s predictive contribution to reading comprehension in Spanish.

4.2.3 Experiment 5: The Current Experiment

The results from *Experiment 1* (Chapter-2) indicated that decoding skills accounted for 21% of variance in reading comprehension for monolingual English readers without dyslexia, while language comprehension skills account for 41% of the variance. In *Experiment 3* (Chapter-3), for readers with dyslexia who were poor at decoding, these decoding skills did not significantly predict reading comprehension while language comprehension accounted for 57% of variance in reading comprehension. Since native reading in a consistent orthography may involve a different pattern of contribution of the skills involved in the SVR, it was expected that results for a group of skilled native Spanish readers (a consistent language) may look different from the pattern found from the native English participants. Specifically, that decoding skills should account for even less of the variance in reading comprehension as compared to language comprehension because decoding skills should be completely mastered in skilled readers. Thus, the goal of the current experiment was to consider the reading components described in the predictions of the SVR and to determine the extent to which decoding, and language comprehension abilities drive the strategies involved in skilled reading in a consistent orthography i.e., Spanish.

For these reasons, in *Experiment 5*, reading abilities were measured in a sample of college aged native Spanish speaking Spanish-English bilingual readers without reading impairments. Bilinguals were chosen for the current experiment so that reading in their native language, which is a consistent orthography, could be investigated, but also so that these strategies could be compared with their reading strategies in an inconsistent language. The measures included the language components such as decoding, language comprehension and reading comprehension from the SVR (Gough & Tunmer, 1986), as well as vocabulary knowledge. The current experiment chose a sample of bilinguals rather than monolinguals to later investigate a comparison of their reading strategies in their native Spanish, with their second language (English). These comparisons will be discussed in the following Chapter-5.

As with *Experiment 1* (Chapter-2) *and Experiment 3* (Chapter-3) in monolingual English readers with and without dyslexia, the current experiment used subtests from the Woodcock-Munoz Language Survey III in Spanish (Woodcock, Alcarado, & Ruef, 2017) to measure language comprehension, decoding skills, reading comprehension and vocabulary knowledge.

4.2.3.1 Hypotheses

The current *Experiment 5* aimed to investigate the following hypotheses:

1. Since decoding skills are mastered early on in development for readers of consistent orthographies (Goswami, 2002; Seymour, Aro, & Erskine, 2003; Florit & Cain, 2011), it was expected that decoding skills should be close to ceiling, and thus language comprehension scores should be better than decoding scores at predicting reading comprehension scores.

2. Contrary to SVR predictions, findings from English samples have reported that the additive model may also be adequate at accounting for variance in reading comprehension (e.g., Connors; 2009, Savage, 2006; Savage & Wolforth, 2007; Dreyer & Katz, 1992; Neuhaus et al., 2006; Tiu, Thompson & Lewis, 2003; Kershaw & Schatschneider, 2012). This has not been directly tested in readers from a consistent orthography, thus the current experiment will directly test both formulas, and it is expected that since decoding stops exerting influence on reading comprehension as readers age, the additive and multiplicative model would be adequate at accounting for reading comprehension, however, the additive model would demonstrate better predictive power than the multiplicative model.

3. As demonstrated in Chapter-2, vocabulary knowledge has been influential additions to the SVR model in previous research in English as well as in consistent languages such as Spanish (Goodwin, August, & Calderon, 2015; Goodrich & Namkung, 2019). A final goal of this experiment was to explore whether vocabulary knowledge could predict reading comprehension above and beyond the SVR components in our Spanish sample, i.e., users of a consistent orthography

4.2.4 Methods

4.2.4.1 Ethics Statement

Both Experiment 5 and 6 were approved by The Institutional Ethical Review Board, University of Brunel London, Department of Psychology, United Kingdom (number IP - IRB/11942-LR-Aug/2018- 13812-2) (see Appendix 1). Written informed consent was obtained from each participant (see Appendix 2b), after participants read an information sheet (see Appendix 2a) about the purpose of the experiment and their right as participants to withdraw at any point in time without giving a reason.

4.2.4.2 Participants

The sample consisted of 38 Spanish-English bilingual readers aged 18-30 (35 females M_{age} = 24.57, SD = 3.67), who were recruited from the University of Granada in Granada, Spain[3]. Participants were recruited via flyers and were awarded 10€ for participation. All participants had normal or corrected-to-normal vision and were native Spanish speakers who reported that they began reading English before the age of 8.

4.2.4.3 Measures and Materials

Analogous Spanish versions of the subtests used in *Experiment 1* (Chapter-2 - WMLS III; Woodcock, Alcarado, & Ruef, 2017) were used to assess participants' language skills in Spanish. These included; vocabulary knowledge (Vocabulario sobre dibujos), decoding skills (Identificación de letras y palabras), language comprehension (Analogías), and reading comprehension (Comprensión de textos).

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[3] This research was supported by the Postgraduate Study Visit Scheme awarded to the PhD candidate of this thesis through the British Psychological Society. With special thanks to Professor Teresa Bajo Molina for her support and the Mind, Brain, and Behavior Research Center at the University of Granada for hosting. Please note that the PhD candidate of this thesis is English-Spanish bilingual.

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Decoding Skills

The WMLS III Identificación de letras y palabras subtest, henceforth referred to as *decoding*, was administered as the measure of Spanish decoding ability (Woodcock, Alcarado, & Ruef, 2017). In this subtest, participants were asked to read a series of increasingly difficult and less-frequent polysyllabic words (e.g., globulariáceas) in Spanish. There were in total 70 items and participants were scored based on the number of correct responses. This subtest has a reported median internal consistency reliability coefficient of .91.

Language Comprehension

The WMLS III Analogías subtest, henceforth referred to as *language comprehension*, was administered to measure language comprehension in Spanish (Woodcock, Alcarado, & Ruef, 2017). In this subtest, the experimenter read the beginning of an analogy and the participant was asked to complete it orally. For example, the experimenter would read "Madre es a Padre, como Hermana es a _____" (Mother is to Father, as Sister is to ___) and the participant should answer with "Hermano" (Brother). This subtest requires listening, reasoning and vocabulary skills to complete each item. There were in total 38 items and participants were scored based on the number of correct responses. This subtest has a reported median internal consistency reliability coefficient of .89

Reading Comprehension

The WMLS III Comprensión de textos subtest, henceforth referred to as *reading comprehension*, was administered as a measure of Spanish reading comprehension, (Woodcock, Alcarado, & Ruef, 2017). In this subtest, participants were presented with a cloze activity where they were asked to silently read a series of passages and supply the missing word for each passage. There were 52 items in total and participants were scored based on the number of correct responses. This subtest has a reported median internal consistency reliability coefficient of .90.

Vocabulary Knowledge

The WMLS III Vocabulario sobre dibujos subtest, henceforth referred to as *vocabulary knowledge*, was used as a measure of Spanish vocabulary knowledge (Woodcock, Alcarado, & Ruef, 2017). In this subtest, participants were shown a series of pictures of objects (e.g., a tricycle) and asked to provide the names of the objects that they see in Spanish. There were in total 52 items and participants were scored based on the number of correct responses. This subtest has a reported median internal consistency reliability coefficient of .86.

4.2.4.4 Procedure

The experiment lasted approximately twenty minutes and was completed in a laboratory at The University of Granada's campus. Upon entering the lab, participants were asked to read a participant information sheet in Spanish (see Appendix 2a) and complete a subsequent written consent form in Spanish (see Appendix 2b) where participants were informed that they were able to withdraw from the experiment at any time without having to give reason. Participants also completed a demographics and language history questionnaire in Spanish (see Appendix 3).

Administration of the WMLS followed the standard procedure outlined in the testing manual. The experimenter began each subtest by reading the instructions and administering two practice items to ensure that the participant understood the directions. Testing then began with an age-appropriate item (since all participants were aged 18 or older and in university, they all began with the same item set). First, a base level was established, if one or more items of the first set of six were incorrect, testing continued with the previous set until all items in a set of six were correct. The item sets prior to the base level were counted as correct responses. Testing then continued with the subsequent sets until six items in a row were answered incorrectly, or when the last item was administered. The number of correct responses was recorded and used for analysis.

After participants finished testing, they were given the participant information sheet in Spanish to provide them with contract details should there be any further questions or problems.

4.2.5 Results

Demographic and language information from the demographics and language history questionnaire are tabulated in Table 23.

Table 23. Demographics Table from Language History Questionnaire for Spanish-English Bilinguals

Measure	*Mean*	*SD*	*Range*
Age (in years)	24.57	3.67	18 - 30
Age of Acquisition (English)	7.05	1.43	3 - 8
Percentage of L1 Use	84.10	15.30	40 - 100
Percentage of L2 Use	16.15	15.37	0 - 60

4.2.5.1 Descriptive Statistics for Spanish-English Bilinguals in Spanish

Means raw scores and standard deviations for each reading ability measure are tabulated in Table 24.

Table 24. Descriptive Statistics for Spanish Language Ability Scores for Spanish-English Bilinguals

			SRs			TSs	
Subtests	N Items	Range	Mean	SD	Range	Mean	SD
Language Comprehension	38	23 - 35	31.53	2.12	xx	31.53	2.12
Decoding Skills	70	68 - 70	69.35	0.73	xx	69.35	0.73

Reading Comprehension	50	38 - 48	43.53	2.38	xx	43.53	2.38
Vocabulary Knowledge	52	33 - 47	40.44	2.78	xx		

4.2.5.2 Correlation Analysis Spanish-English Bilinguals in Spanish

The scores from the WMLS III (Woodcock, Alcarado, & Ruef, 2017) were correlated with Bonferroni corrected alphas of .013. As shown in Table 25, there was a significant positive correlation between language comprehension scores and vocabulary knowledge scores, $r(34) = .47$, $p < .01$, and reading comprehension scores $r(34) = .56$, $p < .001$, but not decoding scores ($r(34) = .32$, $p = .061$). There were no other significant correlations between the variables.

Table 25. Correlations of Spanish WMLS III Scores for Spanish-English Bilinguals in Spanish

	Language Comprehension	Vocabulary Knowledge	Decoding
Vocabulary Knowledge	.47**		
Decoding	.32	-.112	
Reading Comprehension	.56***	.33	.33

Notes: correlation is significant at the $p < .001$***, $p < .01$**, $p < .05$*

These correlations will be explored as regressions in the following sections especially with reference to the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990). Further regressions with Vocabulary Knowledge will be explored. Since several of these measures were highly correlated with one another (see Table 25), we also tested for multicollinearity using the variance inflation factor (VIF). A high degree of multicollinearity poses a problem to the regression because it increases the variance of the regression coefficients, making them unstable. A VIF over 5 indicates high correlation and is generally suggested as a cut-off point (e.g., Simon, 2009). All variables had VIFs < 5, indicating that collinearity was not a problem.

4.2.5.3 Regression Analysis for Spanish-English Bilinguals in Spanish

Simple linear regressions were calculated to see which of the component skills, i.e., decoding skills or language comprehension, predicted reading comprehension separately. As shown in Figure 29 Spanish decoding scores only marginally significantly predicted Spanish reading comprehension ($t(34) = 1.97$, $p = .058$, $R^2 = 0.11$), and explained 11% of the variation in reading comprehension.

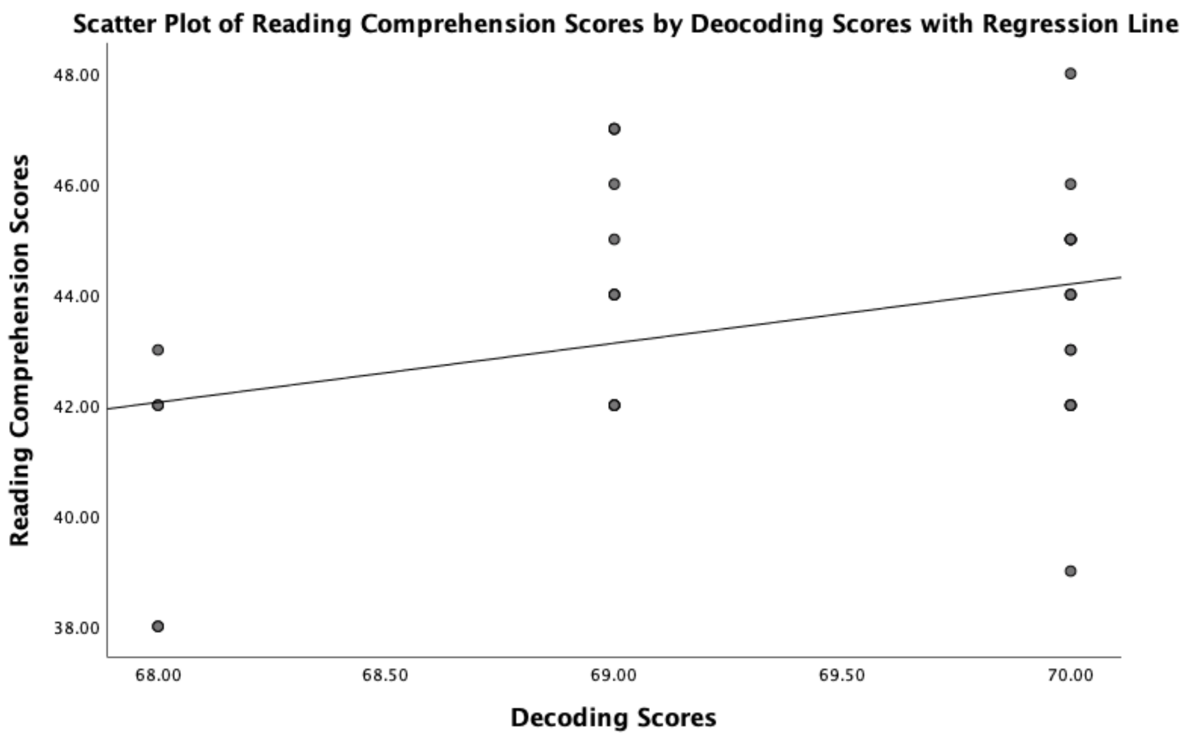

Figure 29. Correlation between Spanish Decoding Scores and Spanish Reading Comprehension Scores for Spanish-English Bilinguals

As shown in Figure 30, language comprehension scores significantly predicted Spanish reading comprehension $t(34) = 3.84$, $p < .001$, $R^2 = 0.32$ and explained 32% of variance for Spanish-English bilinguals reading in Spanish. To be exact, the model predicted that reading comprehension scores would increase by 0.63 points for each additional language comprehension score point.

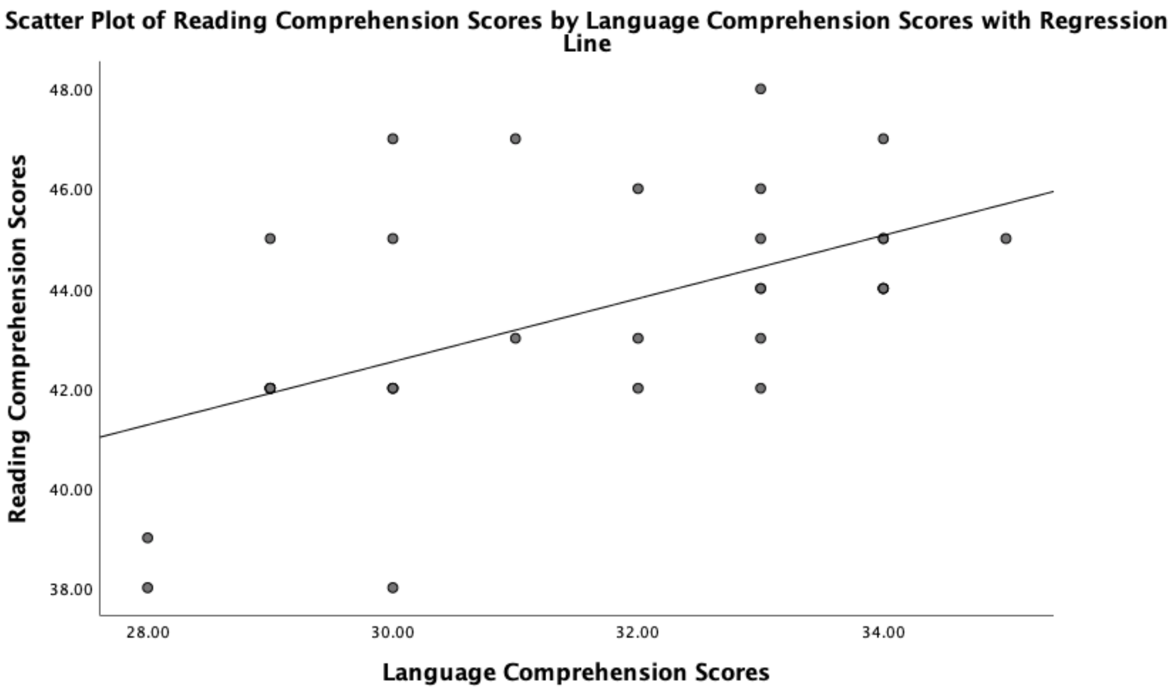

Figure 30. Correlation between Spanish Language Comprehension Scores and Spanish Reading Comprehension Scores for Spanish-English Bilinguals

Next, the pattern of correlations among each reading ability (decoding and language comprehension) was examined using hierarchical regressions to predict reading comprehension.

A hierarchical regression examined whether language comprehension and decoding predicted reading comprehension better than language comprehension alone (Table 26). In Model 1, the overall model was significant $F(1,33) = 14.77$, $p < .001$, $R^2 = 0.32$, such that language comprehension explained 32% of the variation in reading comprehension. Adding decoding to the model did not produce a significant improvement on Model 1, ($\Delta F(1,31) = 1.12$, $p = .298$), however, overall Model 2 was significant $F(2,33) = 7.97$, $p < .01$, $R^2 = 0.34$, and now explained 34% of the variation in reading comprehension ($\Delta R^2 = 2\%$). As shown in

Table 26, language comprehension (β = .51) emerged as a stronger predictor of reading comprehension than decoding (β = .16), which was not a significant predictor.

Table 26. Beta Weights in Hierarchical Regression Model Predicting Spanish Reading Comprehension with the SVR Component Skills for Spanish-English Bilinguals

		B (SE)	**β**	***t***	***p***
Model 1	Constant	23.54 (5.21)			
	Language Comprehension	.63 (.17)	.56	3.84	.000
Model 2	Constant	11.49 (33.48)			
	Language Comprehension	.57 (.17)	.51	3.30	.002
	Decoding	.53 (.50)	.16	1.06	.298

* indicates significant model improvement

4.2.5.4 Simple View of Reading in Spanish

The SVR formula (Gough & Tunmer, 1986) was then computed on these data. The SVR postulates that the multiplicative combination of decoding and language comprehension will be a better predictor of reading comprehension than the linear combination of decoding and language comprehension.

First, the product term of decoding and language comprehension was computed, and a subsequent linear regression was conducted to test the product model RC = D x LC as a predictor of reading comprehension. As shown in Figure 31, the regression revealed that the product model was significant $t(34) = 3.99$ $p < .001$, $R^2 = .33$. and explained 33% of the variance for Spanish-English Bilinguals reading in Spanish.

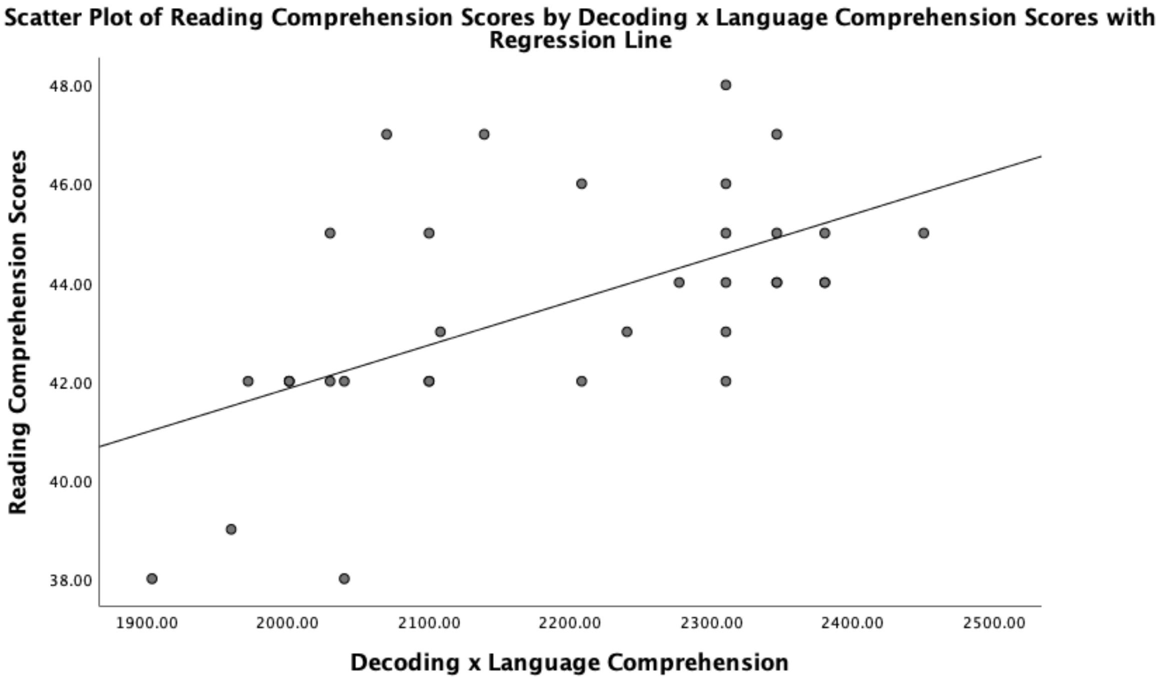

Figure 31. Correlation between the Product of Decoding and Language Comprehension Scores and Reading Comprehension Scores in Spanish for Spanish-English Bilinguals

Next, multiple regressions (Table 27) examined whether the product model would predict unique variance over the linear model of the SVR (Gough & Tunmer, 1986). Decoding and language comprehension were entered singly in the first two steps of regressions as an additive mode with reading comprehension as the outcome variable. The additive model was significant $F(2,12) = 7.15$, $p < .01$, $R^2 = .59$, such that this model explained 59% of the variation in reading comprehension. The addition of the product term as a third step in the regression model yielded an overall significant model, $F(3,12) = 4.53$, $p < .05$, $R^2 = .60$, and accounted for an additional 1% of variance, however this increase was not significant ($\Delta F(1,12) = 0.29$, $p = .602$).

When the same procedure was done in reverse, the product model alone was significant $F(2,12) = 10.85$, $p < .01$, $R^2 = .50$, and the addition of the decoding and language comprehension in the next steps accounted for a non-significant ($\Delta F(2,12) = 1.19$, $p = .349$) additional 10% of the variance in reading comprehension.

Table 27. Beta Weights in Multiple Regression Model Predicting Spanish Reading Comprehension for Spanish-English Bilinguals

		B (SE)	**β**	***t***	***p***
Model 1	Constant	38.92 (18.12)			
	Language Comprehension	.61 (.17)	.82	3.64	.005
	Decoding	.19 (.29)	.15	0.66	.522
Model 2	Constant	64.43 (192.20)			
	Language Comprehension	3.74 (5.80)	5.04	.65	.535
	Decoding	1.34 (2.85)	1.03	.47	.650
	Product (D x LC)	.046 (.086)	4.86	.54	.602
Model 1	Constant	30.45 (4.21)			
	Product (D x LC)	.007 (.00)	.705	3.29	.007
Model 2	Constant	64.43 (192.20)			
	Language Comprehension	3.74 (5.80)	5.04	.65	.535
	Decoding	1.34 (2.85)	1.03	.47	.650
	Product (D x LC)	.046 (.086)	4.86	.54	.602

* indicates significant model improvement

4.2.5.5 Vocabulary Knowledge in Spanish

Vocabulary knowledge has been influential additions to the SVR model in previous research (Goodwin, August, & Calderon, 2015; Goodrich & Namkung, 2019). Thus, vocabulary knowledge was added to the previous models to determine whether this skill could predict reading comprehension above and beyond the component skills in the SVR, i.e., decoding and language comprehension.

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First, a simple linear regression was calculated to see whether Spanish vocabulary knowledge predicted Spanish reading comprehension on its own. As shown in Figure 32, a simple linear regression revealed that vocabulary knowledge was not a significant predictor of reading comprehension ($t(34) = 1.90$, $p = .068$, $R^2 = 0.11$).

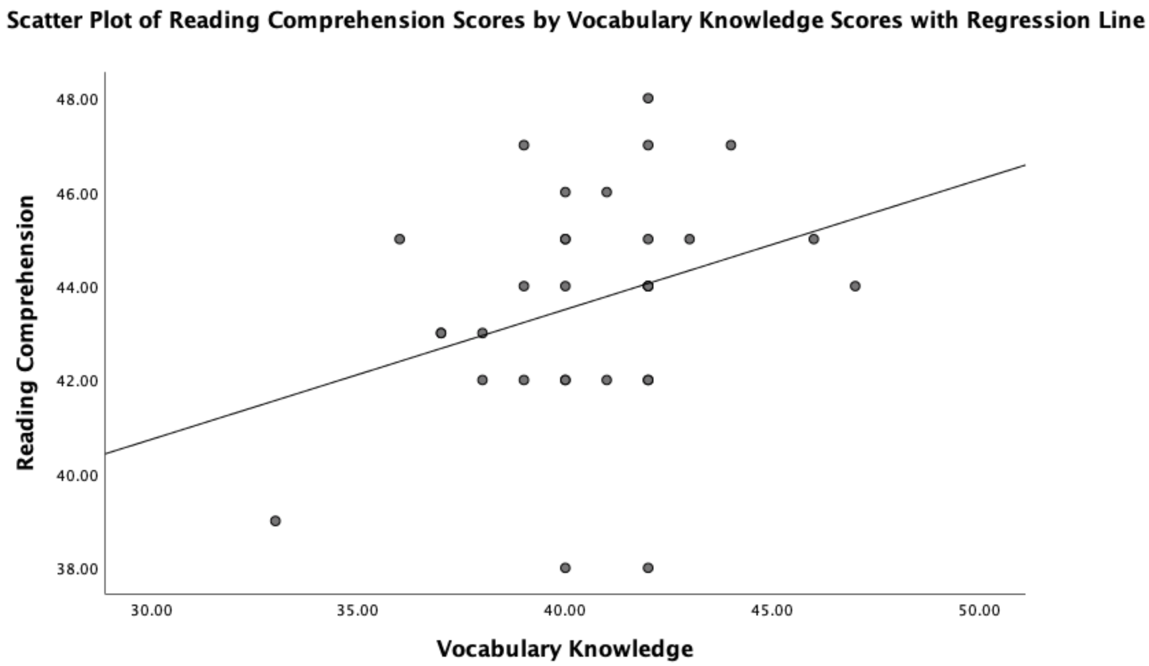

Figure 32. Correlation between Vocabulary Knowledge Scores and Reading Comprehension Scores in Spanish for Spanish-English Bilinguals

Next, vocabulary knowledge was added to the previous hierarchical models which included decoding and language comprehension. Vocabulary knowledge was added as a third step was included to test whether this skill would predict reading comprehension scores above and beyond decoding and language comprehension scores (Table 28). Model 3 did not significantly improve upon Model 2 ($\Delta F(1,30) = 0.77$, $p = .389$), though Model 3 was significant overall $F(3,33) = 4.82$, $p < .01$, $R^2 = 0.34$, and explained 34% of the variance in reading comprehension ($\Delta R^2 = 0.1\%$). As shown in Table 28, language comprehension ($\beta = .41$) emerged as the only significant predictor of reading comprehension, followed by decoding (β = .21) and vocabulary knowledge (β = .16), which were not significant predictors in this model.

Table 28. Beta Weights in Hierarchical Regression Model Predicting Spanish Reading Comprehension with Three Spanish Reading Abilities for Spanish-English Bilinguals

		B (SE)	**β**	***t***	***p***
Model 1	Constant	23.54 (5.21)			
	Language Comprehension	.63 (.17)	.56	3.84	.000
Model 2	Constant	11.49 (33.48)			
	Language Comprehension	.57 (.17)	.51	3.30	.002
	Decoding	.53 (.50)	.16	1.06	.298
Model 3	Constant	24.18 (37.64)			
	Language Comprehension	.48 (.22)	.41	2.14	.041
	Decoding	.68 (.55)	.21	1.24	.226
	Vocabulary Knowledge	.14 (.16)	.16	0.16	.389

* indicates significant model improvement

These same steps were then repeated in reverse, and a hierarchical regression was performed examining whether vocabulary knowledge and language comprehension predicted reading comprehension better than vocabulary knowledge alone (Table 29).

In Model 1, the overall model was not significant ($F(1,33) = 3.60$, $p = .068$, $R^2 = 0.11$). Adding language comprehension to the model produced a significant improvement on Model 1, $\Delta F(1,31) = 5.00$, $p < .01$, such that overall Model 2 was significant $F(2,33) = 6.35$, $p < .01$, $R^2 = 0.31$, and now explained 31% of the variation in reading comprehension ($\Delta R^2 = 20\%$). As shown in Table 29, language comprehension (β = .50) emerged as a stronger predictor of reading comprehension than vocabulary knowledge (β = .09).

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Table 29. Beta Weights in Reverse Hierarchical Regression Model Predicting Spanish Reading Comprehension with Three Spanish Reading Abilities for Spanish-English Bilinguals

		B (SE)	**β**	***t***	***p***
Model 1	Constant	32.02 (6.12)			
	Vocabulary Knowledge	.29 (.15)	.33	1.90	.068
Model 2*	Constant	21.76 (6.55)			
	Vocabulary Knowledge	.08 (.15)	.09	0.52	.067
	Language Comprehension	0.59 (.21)	.50	2.87	.008
Model 3	Constant	24.18 (37.64)			
	Vocabulary Knowledge	.14 (.16)	.16	.88	.389
	Language Comprehension	.48 (.22)	.41	2.14	.041
	Decoding	.68 (.55)	.21	1.24	.226

* indicates significant model improvement

Finally, the third step tested whether decoding scores would predict reading comprehension scores above and beyond language comprehension and vocabulary knowledge scores (Table 29). Model 3 did not significantly improve upon Model 2 ($\Delta F(1,30) = 1.54$, $p = .226$), however, as seen above, this model was significant overall $F(3,33) = 4.82$, $p < .01$, $R^2 = 0.34$, and explained 34% of the variance in reading comprehension. Language comprehension (β = .41) emerged as the only significant predictor of reading comprehension, followed by decoding (β = .21) and vocabulary knowledge (β = .16), which were not significant predictors in this model.

4.2.6 Discussion

The aim of *Experiment 5* was to measure the extent to which the language components (decoding, language comprehension and reading comprehension) described in the SVR

(Gough & Tunmer, 1986; Hoover & Gough, 1990) may contribute to variance in reading comprehension in skilled readers of Spanish, a consistent orthography. Specifically, the current experiment tested whether a multiplicative or an additive model of the SVR could better predict variance in reading comprehension in Spanish. To our knowledge, the SVR model has not been tested on skilled adult readers of Spanish. Of further interest, was the extent to which each of these individual reading abilities as well as vocabulary knowledge, contributed to reading comprehension on their own, and the extent of their relationship to one another. For this reason, four measures of reading skills (decoding, vocabulary knowledge, language comprehension and reading comprehension) were examined in a sample of adult skilled readers of Spanish.

Results revealed that only language comprehension significantly correlated with reading comprehension. The only other significant relationship found was between vocabulary scores and language comprehension scores. Decoding scores did not significantly correlate with any of the other reading variables. Though the SVR proposes that both decoding skills and language comprehension skills make independent contributions to the variance in reading comprehension, the current results still do make sense within the framework of the SVR given that the mean decoding score was almost a perfect score in the current sample of skilled readers (i.e., 69.35 out of 70). In the multiplicative formula (reading comprehension = decoding x language comprehension), the SVR would define a perfect score as decoding = 1 which remains constant (1 x language comprehension = reading comprehension), thus all variation in reading comprehension scores would be based only on the language comprehension component scores.

Language comprehension scores only accounted for 32% of the unique variance in reading comprehension in skilled Spanish-English bilinguals reading in Spanish. The results from the current sample would be inconsistent with the SVR that posits that if decoding = 1, language comprehension should account for all the variance in reading comprehension. Spanish decoding scores in the current sample did not significantly contribute to the variance in reading comprehension alone and did not emerge as a significant predictor in the SVR in the current sample. Similar results have been found in Spanish-speaking children in Grade-4, where Spanish decoding skills were not found to significantly contribute to reading comprehension (Goodwin, August, & Calderon, 2015). These results align with another assertion of the SVR framework, which posits that as readers gain skill, decoding skills should be of lesser importance to the contribution of reading comprehension than language comprehension abilities (Gough & Tunmer, 1986; Hoover & Gough, 1990). It is important to note that the SVR was originally proposed to account for the variance in reading comprehension for children and thus, results from our sample of skilled adult readers in Spanish may differ from a sample of Spanish-native children (Hoover & Gough, 1990).

Since the mean decoding scores were still not perfect scores in the current sample, the multiplicative model of the SVR which included decoding scores, should account for slightly more variance in reading comprehension. This was indeed found to be the case as the multiplicative model of the SVR in the current sample accounted for 33% of the variance in reading comprehension. These results explained slightly less variance in reading comprehension than has been found previous research where the SVR model accounted for between 40% and 68.7% of the variance in reading comprehension for children reading in consistent orthographies (Joshi, Tao, Aaron, & Quiroz, 2012 for Spanish; Caravolas et al., 2019 for Spanish, Slovak, and Czech). However, the lower proportion of explained variance in the current experiment could reflect the fact that this sample consisted of skilled adult readers of Spanish. Research has found that in consistent languages, the magnitude of explained variance in reading comprehension may decrease with increased decoding skill compared to inconsistent languages (Asadi & Ibrahim, 2018; García & Cain, 2014; Caravolas et al., 2019). Such findings stemmed directly from the increase in decoding skills, which advance much quicker for readers of consistent orthographies than those of inconsistent ones and begin to contribute less to variance in reading comprehension as readers of transparent orthographies age. These findings support the ODH (Katz & Frost, 1992) and PGST (Ziegler & Goswami, 2005) that reading is supported by the sub-lexical route to a greater extent in consistent orthographies compared to inconsistent ones. This highlights the strength of decoding skills developed in a consistent language and the importance of decoding skills for readers of inconsistent languages to support reading.

Similar to the sample of English monolingual readers in *Experiment 1* (Chapter-2), the additive model of the SVR accounted for more of the variance in reading comprehension (i.e., 34%) than the multiplicative model (i.e., 32%). However, in *Experiment 1*, the additive model accounted for 45% of the variance in reading comprehension in the English monolingual sample while the model accounted for much less variance in Spanish-English bilinguals reading in Spanish. These results again may reflect the strength of the Spanish decoding skills in the current sample. Once decoding skills are mastered, variance in reading comprehension may be predicted by other variables that are not included in the SVR model, such as vocabulary.

Experiment 1 (Chapter-2) found that vocabulary knowledge also made a significant contribution to the variance in reading comprehension by 6.1% above and beyond that of decoding and language comprehension in skilled native English monolingual readers. The current experiment however did not find evidence that vocabulary knowledge was a significant independent predictor of reading comprehension in Spanish. Vocabulary knowledge also made no significant contributions to variance reading comprehension above and beyond the SVR model. These results are inconsistent with previous research that has found that Spanish decoding skills and vocabulary skills were both significantly correlated with reading comprehension in Spanish (Goodwin, August, & Calderon, 2015; Goodrich & Namkung, 2019). However, these skills were previously only measured in children, where decoding was not yet mastered, whereas the current experiment measured these skills in skilled adult readers. Readers of consistent orthographies may rely to a greater extent on sub-lexical decoding strategies throughout their entire reading experience and as a result, may spend less time building lexical representations in the lexicon. Speculatively, such a pattern could be interpreted to mean that vocabulary knowledge is only as important as the level of decoding skill mastered. Having gained a larger vocabulary storage may enable readers to support reading through a large grain strategy which may be faster if decoding skills are not yet sufficient. As readers gain decoding skill however, vocabulary knowledge may no longer be indicative of an efficient reading strategy. Further studies are needed to investigate the role vocabulary knowledge plays in skilled reading in consistent languages.

4.2.6.1 Limitations and Further Research

The results from the current experiment are informative, yet still limited. In its capacity to predict reading comprehension, the SVR model in our sample failed to account for even half the variance in reading in a consistent language. Future research would benefit from testing a wider variety of skills associated with reading to investigate which skills may be more predictive of reading comprehension for skilled readers of consistent languages. For example, although the phonological system in Spanish is consistent and predictable, Spanish is an inflected synthetic language causing the morphosyntactic system to be quite complex, e.g., the word *(yo) hablo* (I talk) has a new meaning *(él) habló* (he talked) when the last letter is inflected (Comrie, 2009; Defior & Serrano, 2017). Morphological awareness has been found to be an influential aspect of reading in Spanish (Goodwin, August, & Calderon, 2015; Kieffer, Biancarosa & Mancilla-Martinez, 2013). Thus, for Spanish specifically, a model of reading which includes morphological awareness abilities may better predict variance in reading comprehension than the SVR.

Since decoding reaches ceiling accuracy quickly and early on in development for readers of Spanish, it has also been suggested that reading speed may instead be a better indicator of decoding skills in Spanish (e.g., Defior, 2008; Defior et al., 2011; Ripoll et al., 2014).

4.2.6.2 Conclusion

The current experiment (*Experiment 5*) used the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990) as a framework for characterizing the developed skills involved in skilled Spanish reading. Results showed that the SRV accounted for under half of variance in reading comprehension in this sample of Spanish-English bilingual readers, and only language comprehension emerged as a significant predictor of reading comprehension while decoding did not. The additive model of the SVR components was slightly better than the multiplicative model. These findings indicate that the SVR model which was developed for English may not appropriately account for all the variance in reading comprehension in adult readers of Spanish largely due to ease of sub-lexical decoding in a consistent orthography. However, these findings do lend support to the ODH (Katz & Frost, 1992) and PGST (Ziegler & Goswami, 2005) and indicate that strategies differ across orthographies particularly in relation to decoding skills.

4.3 Experiment 6: Eye Movement Patterns in a Consistent Orthography, Spanish

4.3.1 Introduction

The results of *Experiment 2* (Chapter-2) and *Experiment 4* (Chapter-3) demonstrated that for monolingual English readers with and without dyslexia, frequency and length effects were found for early and late eye movement measures, respectively. Thus, there was a differential time-course of word-level effects where word-frequency affected early lexical access and word-length affected later lexical access. However, as discussed previously, according to the ODH (Katz & Frost, 1992), reading strategies may differ depending on the consistency of the orthography being read. Further, the evidence presented above suggests that reading development, and the relative contribution of both decoding and language comprehension to reading comprehension may vary as a function of orthographic consistency. Thus, it is reasonable to assume that eye movement patterns may also be influenced by orthographic consistency. This line of enquiry motivated *Experiment* 6. The current section will review eye movement studies conducted in languages other than English and will offer an argument that eye movements for readers of a consistent orthography would be distinct from those observed in native-English readers because of the nature of the orthography.

4.3.1.1 Eye Movement Patterns in Consistent Orthographies

Eye movement patterns during reading have been extensively investigated in English readers (see Rayner, 2009 for a review). To review briefly, regressions comprise about 10%-15% of all saccades for skilled readers (Starr & Rayner, 2001). On average, fixations last between 200-250ms, but can range from 100ms-500ms for skilled readers of English (see Rayner, 1998 for a review). Fixations are more frequently observed in words with three or more letters and often land at the beginning or the middle of a word depending on word length. While readers fixate on approximately 70% of all the words in a text, around 30% of words are not fixated on. Cross-linguistic studies have been particularly useful in investigating different reading strategies as measured by eye movement patterns exhibited by readers from different orthographies. Some studies have investigated these same eye movements in consistent orthographies. In experiments investigating consistent languages such as German, fixation durations have been reported to last anywhere between 192ms (Hutzler & Wimmer, 2004) to 243ms (Tiffin-Richards & Schroeder, 2015). The number of fixations per 100 words in an inconsistent language such as English were between 75-118 reported by Rayner (1998), while a study in a consistent language (i.e., Dutch) reported average fixations per 100 words to be 72. (Cop et al., 2016). Thus, it seems that readers of a consistent language employ fewer fixations, but may demonstrate a wider range of fixation durations than readers of English.

The development of the component skills described in the SVR may be driven by the orthography of the reader’s native language thereby lending support to the ODH (Katz &

Frost, 1992). Eye movement patterns may provide additional information on reading strategies driven by a reader's orthography based on their relationship with the SVR component skills and offline measures of reading ability. For example, the component reading skills in the SVR have been significantly correlated with eye movement measures such as gaze duration and fixation duration (Barnes, Young-Suk Kim, Tighe & Vorstius, 2017), as well as eye movements and other reading abilities such as reading speed and word knowledge (Inhoff & Rayner, 1998; Everatt & Underwood, 1994; Krieber et al., 2016).

Experiment 2 (Chapter-2) also examined early-stage (first fixation duration and gaze durations) and late state (go-past times and total reading times) eye movement patterns while participants read in an inconsistent orthography. Early-stage eye movements are assumed to reflect initial lexical access while, late measures are assumed to reflect higher order processes such as semantic integration, revision, and ambiguity resolution (Rayner, 1998; Rayner, 2009; Liversedge, Paterson, & Pickering, 1998). These eye movement measures have been examined in cross-linguistic reading experiments where findings suggest they are influenced by orthographic consistency (e.g., Rau, Moll, Snowling & Landerl, 2015). The next section will discuss these findings in further detail.

4.3.1.2 Length and Frequency Effects in Consistent Orthographies

As previously demonstrated in *Experiment 2* (Chapter-2) *and Experiment 4* (Chapter-3), the investigation of length and frequency effects in eye movements may be useful in revealing developed reading strategies. For example, the comparison between English readers with and without dyslexia in *Experiment 4* (Chapter-3) indicated that both groups were sensitive to both length and frequency effects, however, these effects were larger for readers with dyslexia than readers without dyslexia. Further, the time-course of these effects differed between readers with and without dyslexia, such that readers with dyslexia were only sensitive to frequency effects in early measures of reading while readers without dyslexia were sensitive to frequency effects in all eye movement measures. These findings indicate overall slower decoding and semantic integration with an over-reliance on the sub-lexical process for native-English readers with dyslexia compared to readers without dyslexia.

Similar to findings from English, findings from readers of consistent orthographies also report word length effects which are assumed to reflect the use of sub-lexical decoding strategies (e.g., Zoccolotti et al., 2009; Zoccolotti et al., 2005). However, length effects may be larger for readers of a consistent orthography compared to readers of an inconsistent orthography. For example, German readers tend to read short words faster than long words regardless of frequency, compared to readers of English who show a much smaller difference in reading times between short and long words (Goswami, Gombert, & Fraca de Barrera, 1998, Rau, Moll, Snowling & Landerl, 2015). The size of the word length effect may be indicative of the degree with which a sub-lexical decoding strategy is used. Larger word length effects are interpreted to reflect a greater reliance on sub-lexical decoding (e.g., van den Boer, de Jong, & Haentjens-van Meeteren, 2013; Zoccolotti et al., 2009). Typically, in readers of consistent orthography, the word length effect tends to decrease as readers gain reading experience (e.g., di Filippo et al., 2006; Hawelka, Gagl, & Wimmer, 2010; Hutzler & Wimmer, 2004; Martens & de Jong, 2006; Zoccolotti et al., 2009; 2005).

Word length also interacts with word-frequency and lexicality such that the length effect is larger in nonwords compared to real words (e.g., de Luca, Borrelli, Judica, Spinelli, & Zoccolotti, 2002; Martens & de Jong, 2006; Wydell et al., 2012; Zoccolotti et al., 2009) and larger in low-frequency words compared to high-frequency words (e.g., Balota, Cortese, Sergent-Marshall, Spieler, & Yap, 2004; Dürrwächter, Sokolov, Reinhard, Klosinski, & Trauzettel-Klosinski, 2010; Zoccolotti et al., 2009). Thus, if the size of the word length effect indicated that use of the sub-lexical strategy, it follows that the larger word length effect in nonwords than in words and in low compared to high-frequency words indicated that less familiar words require a serial phonological decoding strategy than more familiar words (e.g., Share, 1995, 2008). Thus, these interpretations are similar to those applied to findings from length and frequency effects in English readers or readers from inconsistent orthographies (e.g., Blythe et al., 2011; Joseph, Nation, & Liversedge, 2013; Joseph et al., 2009; White & Liversedge, 2004).

However, as previously discussed in Chapter-1, length and frequency effects may reflect the distinct reading strategy employed by readers, and thus may differ across orthographies lending support to the ODH (Katz & Frost, 1992). Research has reported larger frequency effects (Landerl, Wimmer & Frith, 1997; Rau, Moll, Snowling & Landerl, 2015; Ziegler, et. al., 2001) and lexicality effects (Paulesu et al., 2000), but smaller length effects (Ellis & Hooper, 2001; Goswami, Gombert, & Fraca de Barrera, 1998, Rau, Moll, Snowling & Landerl, 2015; Ziegler, et. al., 2001) for readers of inconsistent orthographies compared to readers of consistent orthographies.

The differences between length and frequency effects across orthographies may be interpreted to reflect the use of either small grain or larger grain reading strategies (Zeigler & Goswami, 2005). According to the PGST (Zeigler & Goswami, 2005), readers of a consistent language may rely on sub-lexical decoding strategies because they are able to reliably process small grains of information from a word at a time (i.e., phonemes) to support successful reading. On the other hand, small grain processing is unreliable in inconsistent orthographies, and thus these readers must employ reading strategies that process larger units at once (i.e., whole-words) through a lexical procedure to reduce ambiguity. Following this account, larger length effects indicate a reliance on small unit decoding strategies. Thus, larger length effects would be expected for readers of consistent orthographies compared to readers of inconsistent orthographies who must use a larger grain size strategy which is not necessarily slowed by length. For the same reason, readers of consistent orthographies may use a small unit decoding strategy to process both high-frequency and low-frequency words at the same rate, whereas the larger unit strategy employed by readers of English is slowed by word-frequency. Based on this account, readers of consistent orthographies are expected to be less sensitive to frequency effects compared to readers of inconsistent orthographies.

Investigating length and frequency effects has been useful in determining the time-course of reading strategies in readers of English. However, this remains an understudied area in consistent languages. To our knowledge, only two studies have investigated these effects using early and late eye movement measures in a consistent language (Rau, Moeller & Landerl, 2014; Rau, Moll, Snowling & Landerl, 2015). The results of these experiments suggest that length and frequency effects observed in readers of consistent and inconsistent orthographies may indicate that reading strategies differ in the time-course of reading.

Rau and colleagues (2014) investigated the transition from a serial sub-lexical processing to a lexical processing reading strategy in native-German readers at varying proficiency levels (Grades 2, 3, and 4, and adults) by examining length, lexicality, and frequency effects in eye movements. Participants were asked to read sentences containing embedded target words which varied in length and frequency or were nonwords while their eye movements were measured. Specifically, gaze durations were measured in this study and the size of the word length effect (e.g., difference in processing time between long and short targets) was used as an indicator of sub-lexical decoding. Length and frequency effects were found for all participants indicating that longer nonwords and words with lower frequency had longer gaze durations than short nonwords and words that were shorter with higher frequency. However larger length effects were reported for the younger less experienced readers for high-frequency words, but were not larger for low-frequency words. Further, length effects over reading experience were modulated by word-frequency such that length effects of words for differing frequencies were comparable for the younger less experienced readers (i.e., no length x frequency effect). However, the older more experienced readers demonstrated increased length effects with decreasing word-frequency. Taken together, the least experienced group of readers appeared to apply a sub-lexical decoding strategy as a default to approach all word types, while the more skilled readers were able to apply lexical strategies primarily to most word types, and only relied on sub-lexical decoding strategies as word-frequency decreased.

A second study by the same research group (Rau et al., 2015) compared reading strategies across orthographic consistency. First fixation durations, gaze durations, and rereading times were measured in groups of native-German and native-English children and adults as they read sentences embedded with target words that were manipulated for length and frequency. Overall, English children did not show longer first fixation durations or gaze durations than German children but did show longer rereading times. However, total reading times were not significantly different indicating that the processing times of early (first fixation duration and gaze duration) and late (rereading and total reading times) reading measures cancelled each other out. Main effects of length were found for gaze durations and rereading times indicating that these eye movements were slower for long words compared to short words (note that there was no length effect for first fixation duration). Main effects of frequency were found for all eye movement measures indicating that as word-frequency increased, these eye movement measures decreased in processing time. Length x frequency interactions indicated larger length effects for first fixation durations, gaze durations and rereading times in low-frequency words compared to high-frequency words. Length effects, but not frequency effects were also significantly larger in early eye movement measures (first fixation durations and gaze durations) for German readers than for English readers. While both length and frequency effects were significantly larger for English than German readers for rereading times (a late eye movement measure), length x frequency interactions indicated that the larger length effects for English readers in rereading times resulted from the effects of the low-frequency words.

For adults, processing times for each eye movement measure did not differ between native-German adults and native-English adults. Similar to the results from children, main effects of length and frequency were found for all reading measures, however there was only a significant length x frequency interaction for gaze durations. Unlike the results reported for children, length effects were not found to be larger for either group in any of the eye movement measures, however frequency effects were significantly larger in gaze durations for native-English readers than native-German readers.

Taken together, the results of this experiment demonstrate that although total reading times did not differ between orthographies, children and adults use different eye movement strategies to achieve similar outcomes. Length effects, but not frequency effects were greater for German than English readers in early eye movement measures of reading for children, while the difference in length effects may disappear for adult readers, but the difference in the size of the frequency effects were more pronounced in adults. These results lend support to both the ODH (Katz & Frost, 1992) by demonstrating a difference in strategies (as measured by eye movements) used to approach a consistent versus an inconsistent language. These results also support the PGST (Zeigler & Goswami, 2005) by demonstrating that readers of consistent languages more frequently rely on small grain reading strategies (as measured by length and frequency effects) compared to readers of inconsistent languages.

Although these findings are informative, this experiment only measured length and frequency effects in one late measure of reading and did not investigate length and frequency effects in total reading times. Go-past times and total reading times are assumed to reflect higher order processes such as semantic integration, revision, and ambiguity resolution (Rayner, 1998; Rayner, 2009; Liversedge, Paterson, & Pickering, 1998) and in native English readers without dyslexia (*Experiment 2*, Chapter-2), these eye movements were found to be affected by both length and frequency. Thus, the current experiment aimed to extend the findings reported by Rau and colleagues (2015), by including both eye movement measures as well as first fixation durations and gaze durations when investigating reading strategies in native readers of Spanish.

Another goal of the current experiment was to investigate whether eye movement patterns may reflect the developed component skills described in the SVR and measured in *Experiment 5* in the current Chapter.

Indeed, reading skill may predict eye movement patterns for readers of consistent languages. For instance, Krieber et al. (2016) investigated eye movements in German adolescent readers aged 13, while they participated in three different reading tasks: silently reading words, texts, and pseudowords. Speed and accuracy were measured from these reading tasks and used as predictors of several eye movements including total reading time, first fixation duration, average fixation duration, gaze duration, number of fixations per word, total number of saccades, total number of regressions, percentage of regressions and saccadic amplitude. Similar to results reported in studies with English readers, better reading skills were associated with more efficient eye movement strategies primarily linked to spatial parameters such as number of fixations per word, total number of saccades, and saccade amplitudes in German readers. Reading speed was found to be a better predictor of eye movement patterns than reading comprehension accuracy. However, unlike findings from English readers, reading skills of German readers were not correlated with temporal eye movement measures (i.e., gaze duration, fixation duration, and total reading time) nor with the number of regressions made during any of the reading tasks. These results were interpreted to indicate that some reading skills are associated with eye movement measures regardless of orthography, but some eye movements, particularly temporal eye movements may vary with orthographic consistency.

For this reason, the current experiment investigated eye movement patterns in skilled readers of Spanish (a consistent orthography) to examine whether there would be differences between eye movement patterns in Spanish compared to English, and whether these patterns could be predictive of the component skills indicated in the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990).

4.3.2 Experiment 6: The Current Experiment

The first goal of the current experiment was to produce an on-line record of reading strategies measured by eye movements employed by adult native Spanish readers reading in Spanish as they process full sentences embedded with target words manipulated for length and frequency, while also being instructed to extract meaning. A second aim of the current experiment was to compare the time-course of these reading strategies as reflected by eye movement measures between native readers of Spanish and native readers of English. Both studies will expand on previous reports of length and frequency effects between consistent and inconsistent orthographies by demonstrating the time-course of the effects using both early and late eye-movement measures.

A final goal of the current experiment was to compare these online measures with the component measures from the SVR that were measured offline. These analyses will provide a further understanding of developed component skills and their relationship to cognitive processes involved in reading as measured by eye movement strategies in a consistent language.

4.3.2.1 Hypotheses

The current experiment aimed to investigate the following hypotheses:

1. Compared to the typical eye movements frequently reported for readers of English (Rayner, 1998), readers of a consistent language may employ fewer fixations, but demonstrate a wider range of fixation durations than readers of English (e.g., Cop et al., 2016; Hutzler & Wimmer, 2004; Tiffin-Richards & Schroeder, 2015). The current study expected to find the same pattern of results.

2. Rau et al. (2014) found both length and frequency effects in gaze durations for adult readers of German but found larger length effects for low-frequency compared to high-frequency words. The current experiment expected to find the same for late eye movement measures that may reflect late lexical access (i.e. go-past time and total reading time), but expect that early measures of lexical access (i.e., first fixation duration and gaze durations) should be sensitive to frequency effects regardless of length.

3. Rau et al. (2015) reported larger length effects for children but not adult readers of German, a consistent orthography compared to readers of an inconsistent orthography. For adults, however, frequency effects were larger for readers of inconsistent orthographies. Thus, in the current sample of adult Spanish-English readers, it was expected that length effects would be larger while reading in Spanish, but frequency effects would be larger for while reading in English.

4. Eye movement measures such as fixation count and fixation duration are considered to reflect decoding strategies (e.g., Rayner, Slattery, Drieghe, & Liversedge, 2011) and thus it was expected that these eye movements measured at the sentence-level would significantly correlate with the decoding scores measured in *Experiment 5* in this Chapter. Total reading time and regressions on the other hand should correlate with higher order language measures such as vocabulary, language comprehension and reading comprehension (e.g., Liversedge, Paterson, & Pickering, 1998; Rayner, 1998).

5. Since the behavioural data from *Experiment 5* in this Chapter demonstrated that language comprehension skills were better predictors of reading comprehension than decoding, it was predicted that late eye movement measures of reading measured at the word-level (i.e., go-past time and total reading time, thought to reflect higher order language skills) would be better predictors of reading comprehension abilities

(as measured in *Experiment 5*) than early eye movement measures of reading in this sample.

4.3.3 Methods

4.3.3.1 Participants

The same 38 Spanish-English bilingual readers aged 18-30 (35 females M_{age} = 24.57, SD = 3.67) from the previous *Experiment 5* in the current Chapter participated in current *Experiment 6* who were recruited from the University of Granada in Granada, Spain.

4.3.3.2 Measures and Materials

50 experimental and 5 practice Spanish sentences were used as the stimuli used in the eye-tracking portion of the experiment (see Appendix 6). The sentences were matched for length to the English sentences from *Experiment 2* (Chapter-2) and contained 12-15 words (*M* = 13.14). Words were also coded and matched to the English sentences used in *Experiment 2* (Chapter-2) on total number of words, word length, and word-frequency. Frequency information was obtained via the Zipf scale (van Heuven, Mandera, Keuleers, & Brysbaert, 2014) obtained from the norms from the SUBTLEX-ESP database (Cuetos, Glez-Nosti, Barbón & Brysbaert, 2011). To ensure eye movements could be compared across sentences in each language, we tested whether there were significant differences between Spanish sentences and English sentences in terms of these characteristics. An independent-samples t-test showed no significant differences between Spanish sentences and English sentences in terms of length of the sentence $t(46) = 1.35$, $p > .05$, number of letters per word $t(46) = 0.71$, $p > .05$, and average word frequency $t(46) = 0.86$, $p > .05$.

As was done in *Experiment 2* (Chapter-2) *and Experiment 4* (Chapter-3), 40 pairs of high-frequency and low-frequency Spanish words were chosen from these sentences as targets for the word-level analyses. These targets were also matched for length and frequency to the targets used in the English sentences. Targets were embedded in the sentences that participants read, and excluded first and final words in the sentences; function, punctuated, and repeated words; proper nouns; and words with cross-language orthographic overlap, such as cognates and interlingual homographs (e.g., Miellet et al., 2007; Pollatsek et al., 2006; Whitford & Titone, 2012; 2014; 2017). Frequency information for the targets was again measured via the Zipf scale (van Heuven, Mandera, Keuleers, & Brysbaert, 2014) obtained from the norms from the SUBTLEX-ESP database (Cuetos, Glez-Nosti, Barbón & Brysbaert, 2011). High-frequency targets had a mean Zipf of (5.49) and low-frequency targets had a Zipf of (2.83). The high-frequency and low-frequency words were further divided into short and long words. There were an equal number of short words consisting of 3-5 letters (*M* = 4.36) and long words consisting of 6-11 letters (*M* = 7.82).

The TRUE–FALSE comprehension questions from *Experiment 2* (Chapter-2) were also translated and used to ensure the participants processed the meaning of the sentences and were paying attention. Data was only included from the participants who answered correctly on at least 80% of the comprehension questions.

4.3.3.3 Apparatus

Participants' eye-movements were recorded using an Eyelink 1000 (SR Research, 2010) Desktop Mount eye-tracking device (the same model as used in *Experiment 2 and 4* at Brunel University London, UK) at a sampling rate of 2000 Hz and spatial resolution of less than 0.02-degree visual angle, which recorded the position of the reader's eye every half millisecond. Participants were seated 60 cm away from a monitor (with a refresh rate of 100 Hz) on which the stimuli were presented using E-Prime software (Psychology Software Tools, Pittsburgh, PA).

4.3.3.4 Procedure

The procedure of the current experiment was identical to that of *Experiment 2* (Chapter-2) *and Experiment 4* (Chapter-3) (eye-tracking experiment with English participants with and without dyslexia).

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The experiment lasted approximately forty minutes and was completed in a laboratory on the University of Granada's campus.

4.3.4 Results

After eye-tracking data had been collected the same cleaning procedure as was used in the pilot experiment (Chapter-2) was used in the current experiment to remove very short (< 80 ms) or very long fixations (> 1,000 ms) (Inhoff & Radach, 1998; Liversedge, Paterson, & Pickering, 1998). Targets that received no fixation in first-pass reading were excluded from analyses for all measures of processing time. Total data loss was 11.12%.

Four reading time measures (in milliseconds) were computed: first fixation duration, gaze duration, go-past times and total fixation time (see Table 8 for the definitions of each of these measures).

The current experiment investigated eye movement patterns in native Spanish speaking Spanish-English bilingual readers while reading sentences for meaning in Spanish. Before eye movement measures were analysed, the TRUE-FALSE critical comprehension scores for the sentences for each participant were calculated. All participants scored an 80% or higher and thus no participant was excluded from analysis.

4.3.4.1 Sentence-Level Measures for Spanish-English Bilinguals in Spanish

Means and standard deviations for each eye movement measure are tabulated in Table 30. These scores were calculated based on average scores across the entirety of each sentence.

Table 30. Mean Eye-Movement Measures Across Sentences for Spanish-English Bilinguals Reading in Spanish

Measure	Fixation Count	Average Fixation Duration (ms)	Regression Count	Total Reading Time (ms)

Mean (SD)	11.78 (3.30)	184.33 (12.09)	4.38 (1.49)	2665.26 (739.95)
Range	9.21 - 14.64	147.51 - 210.35	3.67 - 8.92	2134.41 - 4925.87

4.3.4.2 Word-Level Measures for Spanish-English Bilinguals in Spanish

To investigate word-level effects on eye movement strategies, a 2 (frequency: low vs high) x 2 (length: long vs short) repeated measures ANOVA was conducted for each of the four eye movement measures (First fixation duration, gaze duration, go-past time, and total reading time) with Bonferroni corrected alphas of .013 to investigate the effects of length and frequency for Spanish-English bilinguals reading in Spanish. Table 31 depicts the mean measures.

Table 31. Mean Eye-Movement Measures for Frequency x Length for Spanish-English Bilinguals Reading in Spanish

Measure Mean (SD)	First Fixation Duration	Gaze Duration	Go-Past Times	Total Reading Times
HF_Short Words	184.45 (17.35)	207.75 (32.57)	197.92 (25.94)	259.69 (54.94)
LF_Short Words	194.57 (40.14)	234.85 (64.79)	193.43 (42.61)	278.35 (76.67)
HF_Long Words	186.93 (14.51)	233.78 (48.33)	220.47 (53.80)	325.45 (91.39)
LF_Long Words	194.48 (18.53)	279.10 (77.72)	269.33 (82.58)	383.41 (143.14)

There was a significant main effect of frequency for all the eye movement measures. Specifically, as seen in Table 31, shorter first fixation durations $F(1,37) = 12.25$, $p < .001$, gaze durations $F(1,37) = 35.28$, $p < .001$, go-past reading times $F(1,37) = 10.47$, $p < .01$, and total reading times $F(1,37) = 22.29$, $p < .001$, were exhibited for high-frequency compared to infrequent words.

There was also a significant main effect of length for all eye movement measures except first fixation duration. Specifically, as seen in Table 31, shorter, gaze durations $F(1,37) = 12.66$, $p < .01$, go-past times $F(1,37) = 9.95$, $p < .01$, and total reading time $F(1,37) = 45.48$, $p < .001$, were exhibited for short compared to long words. There was no significant difference in first fixation durations ($F(1,37) = 0.12$, $p = .742$), between short and long words.

There was also a significant interaction between length and frequency for all the eye movement measures. Specifically, as seen in Figures 33-36, there was a significant interaction for go-past times $F(1,37) = 11.97$, $p < .01$ and total reading times $F(1,37) = 6.59$, $p = .012$. These interactions indicate that there was only an effect of frequency for long words, but not short words. There was no significant interaction effect for first fixation durations ($F(1,37) = 0.18$, $p = .627$), nor gaze durations ($F(1,37) = 2.91$, $p = .097$).

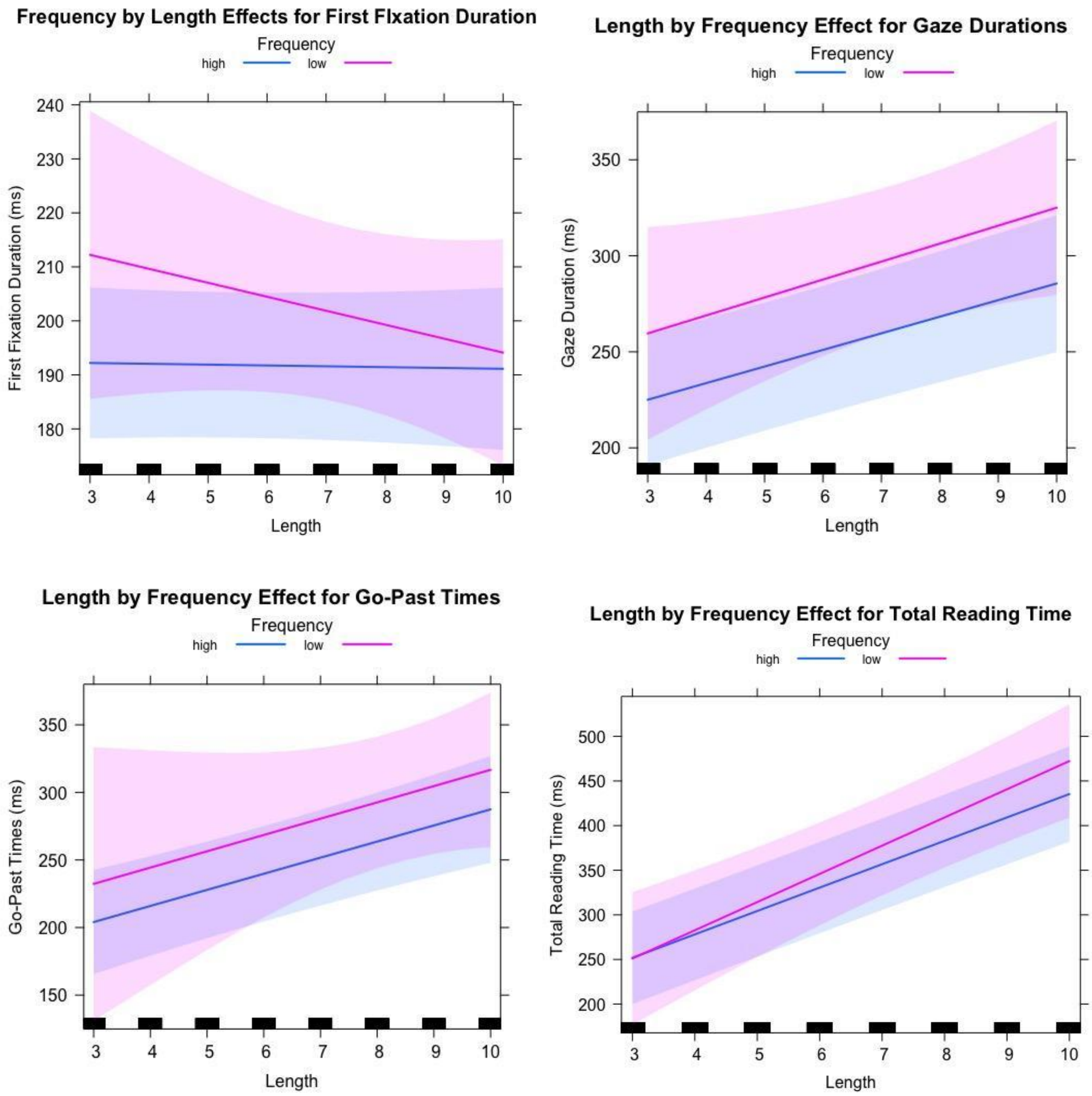

Figure 33, 34, 35, and 36. Length and Frequency Effects in Spanish-English Bilinguals Reading in Spanish.

4.3.4.3 Group comparisons for Word Level Measures between Spanish-English Bilinguals Reading in Spanish and Native-English Readers without Dyslexia from Experiment 2 (Chapter-2)

To analyse whether length and frequency effects were smaller or larger for native-English Readers vs. Spanish-English bilinguals reading in Spanish, a 2 (Orthography; English vs Spanish) x 2 (Frequency; high vs. low) x 2 (Length; short vs. long) between-subjects ANOVA was computed on each of the eye movement measures with Bonferroni corrected alphas of

.013. Main effects of orthography and significant interactions are reported. Although participants in each group were reading in two different languages, the sentences and the targets were carefully controlled and matched for average word length and sentence length and average word-frequency.

First Fixation Durations There was a significant main effect of orthography for first fixation durations $F(1,344) = 60.44$, $p < .001$. Bilingual readers in Spanish had faster first fixation durations ($M = 188.20$, $SD = 19.07$) compared to native-English readers ($M = 210.48$, $SD = 30.35$).

There was a significant length x frequency interaction for first fixation durations $F(1,344) = 0.60$, $p < .011$. As seen in Figure 37, there was no length effect for high-frequency words ($M_{short} = 197.59$, $SD_{short} = 27.33$;. $M_{Long} = 194.13$, $SD_{Long} = 19.78$), but there was a significant length effect for low-frequency words ($M_{short} = 204.19$, $SD_{short} = 35.29$;. $M_{Long} = 211.51$, $SD_{Long} = 28.86$).

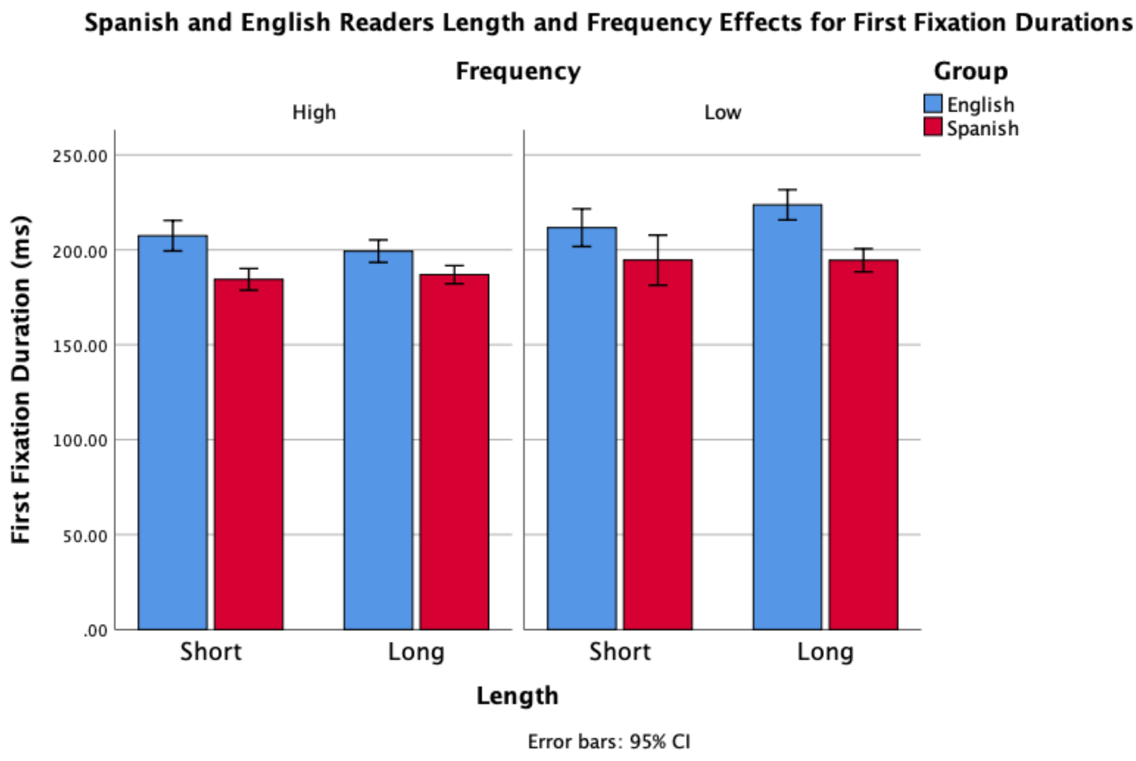

Figure 37. Length and Frequency Effects for First Fixation Durations between Spanish-English Bilinguals Reading in Spanish and Monolingual English Readers

Gaze Durations There was a main effect of orthography for gaze durations $F(1,344) = 18.61$, $p < .001$. Bilinguals reading in Spanish exhibited significantly shorter gaze durations ($M = 237.74$, $SD = 60.20$) compared to native-English readers ($M = 262.04$, $SD = 56.85$).

There was a significant length x frequency interaction for gaze durations $F(1,344) = 8.13$ $p < .01$. As seen in Figure 38, there was no significant effect of length for high-frequency words ($M_{short} = 232.03$, $SD_{short} = 46.81$;. $M_{Long} = 234.59$, $SD_{Long} = 43.24$) and however there was a significant effect of length for low-frequency words ($M_{short} = 254.78$, $SD_{short} = 60.52$;. $M_{Long} = 288.85$, $SD_{Long} = 66.30$).

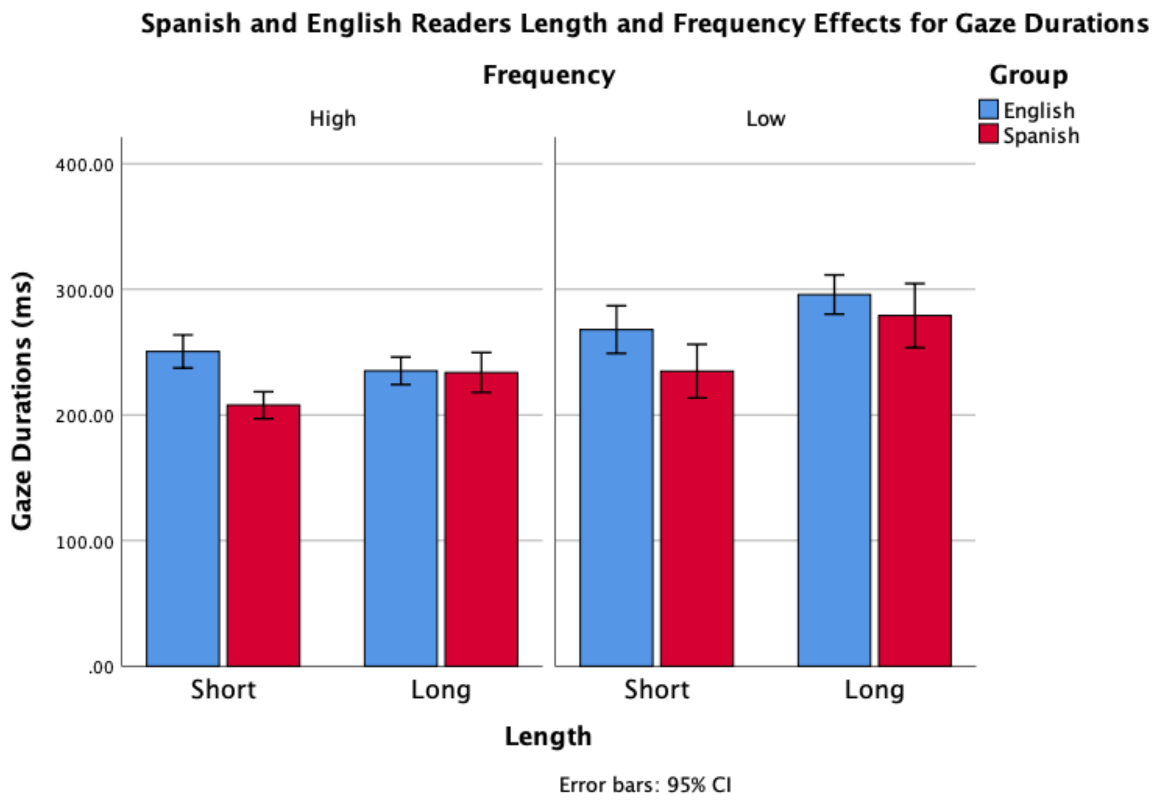

Figure 38. Length and Frequency Effects for Gaze Durations between Spanish-English Bilinguals Reading in Spanish and Monolingual English Readers

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Go-Past Times A main effect of orthography was found for go-past times $F(1,344) = 7.52$, $p < .01$. Bilingual readers in Spanish had significantly longer go-past times ($M = 266.17$, $SD = 72.81$) compared to English readers ($M = 243.99$, $SD = 75.78$).

There was a significant length x frequency interaction for go-past times, $F(1,344) = 9.87$, $p < .01$. As seen in Figure 39, there was no length effect for high-frequency words, but there was a length effect for low-frequency words. High-frequency short words did not have significantly faster go-past times than high-frequency long words ($M_{short} = 212.59$, $SD_{short} = 56.65$;. $M_{long} = 226.46$, $SD_{long} = 72.81$), however, low-frequency short words did have significantly faster go-past times than low-frequency long words ($M_{short} = 223.61$, $SD_{long} = 73.47$; $M_{short} = 282.26$, $SD_{long} = 90.94$).

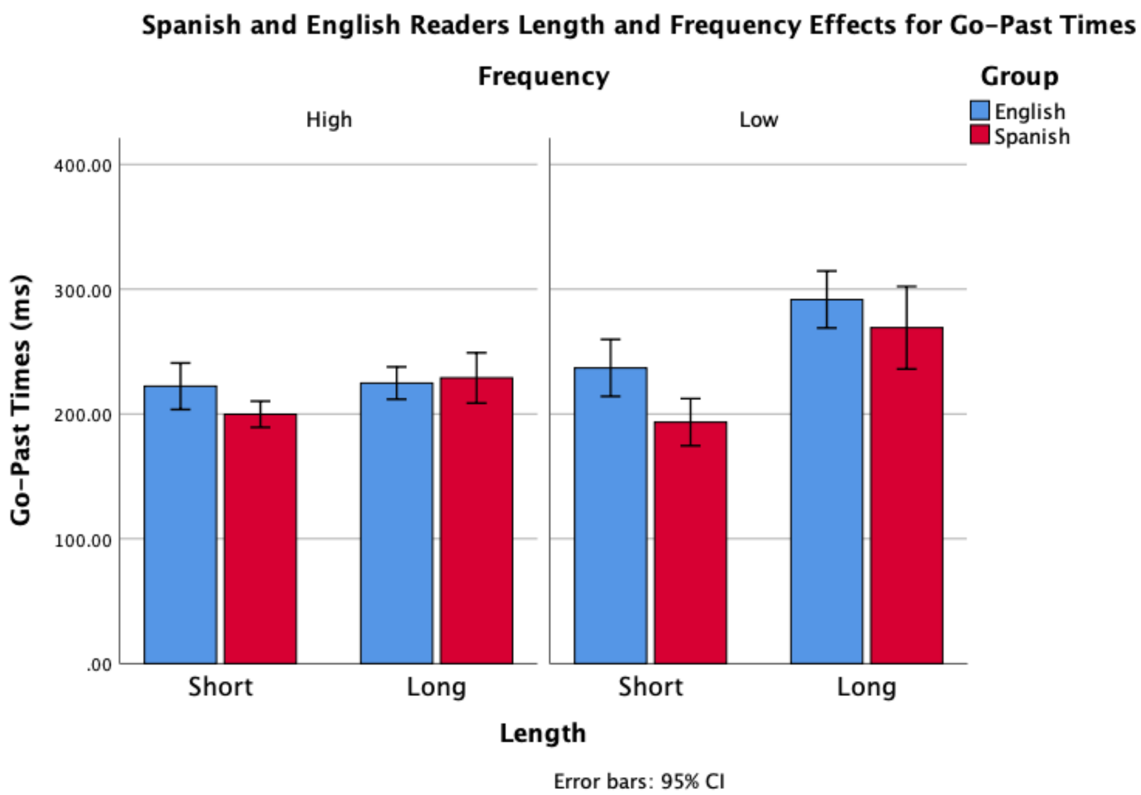

Figure 39. Length and Frequency Effects for Go-Past Times between Spanish-English Bilinguals Reading in Spanish and Monolingual English Readers

Reading Behaviour Between a Consistent and an Inconsistent Orthography

Total Reading Times There was a significant main effect of orthography for total reading times $F(1,344) = 68.06$, $p < .001$ such that bilingual readers in Spanish ($M = 338.58$, $SD = 131.14$), had shorter total reading times compared to native-English readers ($M = 453.14$, $SD = 143.86$).

There was a significant length x frequency effect $F(1,344) = 5.10$, $p < .012$. As seen in Figure 40, there was no frequency effect for short words ($M_{HF} = 341.94$, $SD_{HF} = 125.30$; $M_{LF} = 389.53$, $SD_{LF} = 133.75$), but there was a frequency effect for long words ($M_{HF} = 396.87$, $SD_{HF} = 127.71$; $M_{LF} = 500.16$, $SD_{LF} = 161.67$).

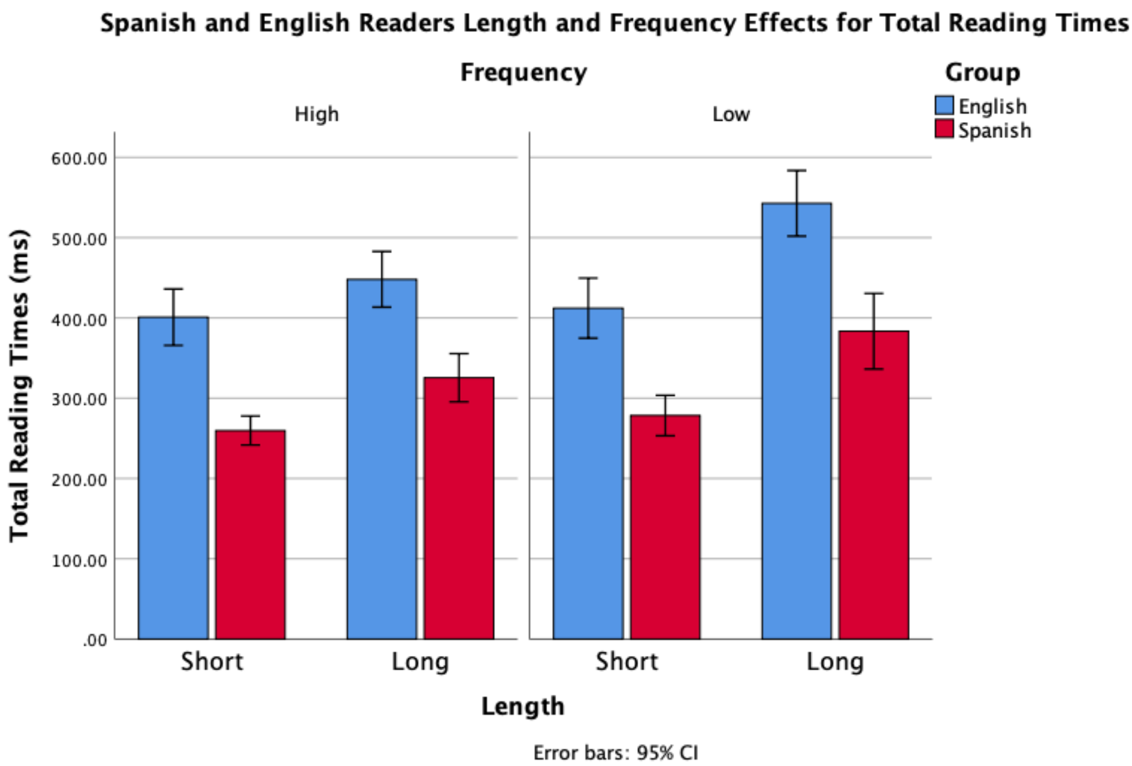

Figure 40. Length and Frequency Effects for Total Reading Times between Spanish-English Bilinguals Reading in Spanish and Monolingual English Readers

4.3.4.5 Eye Movement Patterns and Behavioural Measures in Spanish reading

As with *Experiment 2* (Chapter-2) *and Experiment 4* (Chapter-3) in English readers with and without dyslexia, to test whether the behavioural measures were related to eye movement patterns, a series of correlations between each eye movement measure and each language ability measure from the WMLS III that were measured in *Experiment 5* in this Chapter were computed.

Sentence-Level Measures for Spanish-English Bilinguals in Spanish

First, reading ability scores were correlated with the whole sentence eye movement measures (average fixation duration, total fixation count, regression count, and total reading time) with Bonferroni corrected alphas of .013. No significant correlations were found between these eye movement measures and any of the WMLS III Spanish reading ability scores.

Word-Level Measures for Spanish-English Bilinguals in Spanish

Next, reading ability scores were correlated with the word level eye movement measures (first fixation duration, gaze duration, go-past time, and total reading time) with Bonferroni corrected alphas of .003. No significant correlations were found between these eye movement measures and the WMLS III Spanish reading ability scores.

4.3.5 Discussion

The goal of the current experiment was to examine reading strategies as measured by eye movements in skilled native readers of a consistent orthography and to compare these measures to the reading abilities measured in *Experiment 5* in the current Chapter. The current experiment also aimed to compare these strategies with native readers of an inconsistent orthography.

Compared to the typical eye movements frequently reported for readers of English (Rayner, 1998), it was expected (Hypothesis-1) that Spanish-English bilinguals reading in Spanish, a consistent language may employ fewer fixations, but demonstrate a wider range of fixation durations compared to native-English readers reading in English (e.g., Cop et al., 2016; Hutzler & Wimmer, 2004; Tiffin-Richards & Schroeder, 2015). This hypothesis was indeed supported.

Reading Behaviour Between a Consistent and an Inconsistent Orthography

The current experiment expected that late eye movement measures which may reflect late lexical access (i.e., go-past time and total reading time) would be sensitive to length and frequency effects, but that length effects would be larger for low-frequency words. In contrast, it was expected that early measures of lexical access (i.e., first fixation duration and gaze durations) should be sensitive to frequency effects regardless of length (Hypothesis-2). Results confirmed these predictions and found significant length effects for nearly all the eye movement measures apart from first fixation durations and significant frequency effects for all the eye movement measures. However, there were also significant length x frequency interactions for go-past times and total reading times which indicated that there was only an effect of frequency for long words, but not short words for these eye movement measures.

Frequency effects were also predicted to be smaller for Spanish-English bilingual readers in Spanish compared to native-English readers, while there was not expected to be a significant difference in the size of the length effect between these orthographies (Hypothesis-3). This hypothesis was somewhat confirmed. Frequency effects were indeed smaller for Spanish-English bilinguals reading in Spanish, compared to readers of English for each of the eye movement measures, although these effects did not reach statistical significance. Length effects also tended to be larger for Spanish-English bilinguals reading in Spanish compared to readers of English, and in the case of gaze durations, this effect reached statistical significance.

It was expected that fixation count and fixation duration would significantly correlate with the decoding scores measured in *Experiment 5* in the current Chapter while total reading time and regressions should correlate with higher order language measures such as vocabulary, language comprehension and reading comprehension (Hypothesis-4). This hypothesis was not supported, and no significant correlations were found.

Finally, since the behavioural data from *Experiment 5* in the current Chapter demonstrated that language comprehension skills were better predictors of reading comprehension, it was predicted that late eye movement measures of reading measured at the word-level (i.e., go-past time and total reading time, thought to reflect higher order language skills) would be better predictors of reading comprehension abilities (as measured in *Experiment 5*) than early eye movement measures of reading in this sample (Hypothesis-5*)*. This hypothesis was not supported, and no significant correlations were found.

These findings and their implications will be further discussed below with a discussion on how these results fit within the current literature.

4.3.5.1 Eye Movement Strategies of Native-Spanish Readers

Sentence-Level Measures

To test Hypothesis-1, fixation count, fixation duration, regression count, and total reading times were analysed at the sentence-level for native-Spanish readers. The results from sentence-level analyses indicated that Spanish-English bilinguals' average fixation durations (184.33 ms) were markedly shorter with a wider range (147.51 - 210.35) as they read in Spanish compared the range typically observed in skilled adult readers of English, which is 200–250 ms (Rayner, 1998; Rayner et al., 2006; 1989). However, these findings may not be surprising given that some eye-tracking experiments conducted in consistent orthographies have reported a wider range of average fixation durations from 192ms in German (Hutzler & Wimmer, 2004) to 243ms in German (Tiffin-Richards & Schroeder, 2015). However, the number of fixations per 100 words (104.01) in the current experiment landed within the range of 75-118 reported by Rayner (1998) for English readers, but greater than those reported by a study in a consistent orthography 72 in Dutch (Cop et al., 2016). Further data from consistent orthographies is needed to construct a reliable range of fixation durations and number of average fixations.

The proportion of regressive saccades in the current sample of Spanish-English bilingual readers reading in Spanish was 36%, which was much higher than the 10%-15% reported by Rayner (1998) in English. Again, studies investigating consistent orthographies have reported a wide range of proportion of regressions from 9% in German (Hutzler & Wimmer, 2004) to 24% in Dutch (Cop et al., 2016), and studies from consistent orthographies have reported that regressions do not always correlate with reading comprehension (Krieber et al., 2016). Further data is needed to produce a reliable range.

The results from the current experiment indicates a pattern of shorter, but more frequent fixations and regressions which may be indicative of a decoding strategy of reading for the Spanish-English bilinguals reading in Spanish (Rayner, 1998, Rayner, 2009; Liversedge, Paterson, & Pickering, 1998, Korneev, Matveevn, & Akhutina, 2020). These findings would make sense within the PSGT (Ziegler & Goswami, 2005) and the HGT (Wydell & Butterwoth, 1991) which assert that reading can be supported by small grain processing (i.e., processing graphemes and phonemes rather than rimes and whole-words at a time) if the grapheme-phoneme conversion is consistent, as well as the ODH (Katz & Frost, 1992) which states that reading strategies can follow either a lexical or sub-lexical pathway to support reading depending on the consistency of the orthography. It is important to note here however, that eye movements can vary considerably between readers, and across different kinds of texts (i.e., texts that vary in difficulty or print quality) (Rayner, 1998). For this reason, it is difficult to draw definitive conclusions between different studies.

Word-Level Measures

To test Hypothesis-2, early and late eye movements including first fixation duration, gaze duration, go-past times, and total reading times were analysed for target words that were manipulated for length and frequency embedded in sentences were analysed for Spanish-English bilinguals reading in Spanish. Previous findings have reported that readers of inconsistent orthographies tend to show both word length and word-frequency effects, and that these effects may be indicative of a reliance on both lexical and sub-lexical reading strategies. For example, readers of consistent orthographies tend to read short words faster than long words regardless of frequency, which is indicative of sub-lexical decoding strategy (Goswami, Gombert, & Fraca de Barrera, 1998; Landerl, Wimmer & Frith, 1997; Rau, Moll, Snowling & Landerl, 2015). The word length effect has been reported to decrease as readers gain reading experience indicating the involvement of lexical reading (e.g., di Filippo, de Luca, Judica, Spinelli, & Zoccolotti, 2006; Hawelka, Gagl, & Wimmer, 2010; Hutzler & Wimmer, 2004; Martens & de Jong, 2006; Zoccolotti et al., 2009; 2005). Word length also interacts with word-frequency such that length effects are larger in low-frequency words compared to high-frequency words (e.g., Balota, Cortese, Sergent-Marshall, Spieler, & Yap, 2004; Dürrwächter, Sokolov, Reinhard, Klosinski, & Trauzettel-Klosinski, 2010; Zoccolotti et al., 2009), thus word length effects are modulated by word-frequency.

Findings from the current study accord with these previous findings, but also extend these results by demonstrating the time-course of these effects from early and late eye movement patterns. Specifically, frequency effects were apparent in all eye movement measures, and length effects were found in all eye movement measures except first fixation duration indicating a use of both a lexical and sub-lexical strategy. However, the significant interactions between length and frequency indicated that length effects were found for both low-frequency and high-frequency words, but there was only an effect of frequency for long words in the late measures of reading (i.e., go-past times and total reading times) indicating a greater use of a sub-lexical procedure. This same interaction was not found to be significant for gaze durations or first fixation durations, although the pattern was similar for gaze durations. In the case of first fixation durations however, although not significant, frequency effects were actually larger for short compared to long words, and length effects were only found for low-frequency words such that first fixation durations actually decreased as word length increased.

Taken together, these results suggest that eye movement measures that reflect early lexical access are sensitive to word-frequency for both short and long words. First fixation durations were only sensitive to frequency effects and not length effects, this may suggest that a lexical procedure may be automatically applied based on early lexical information. Since frequency effects in early eye movement measures were only found for short words, this suggests that if the word was short, a lexical strategy may have been deployed based on early lexical information (i.e., first fixation durations and gaze durations) which minimised the need for longer processing in the late eye movement measures of lexical access which showed no frequency effect for short words. However, if words were low-frequency, word length determined whether the lexical or sub-lexical procedure was employed such that the longer the word, the more likely the sub-lexical procedure would be used. Similar results have been reported for other readers of consistent orthographies (Goswami, Gombert, & Fraca de Barrera, 1998, Rau, Moll, Snowling & Landerl, 2015). An interesting finding is that the sub-lexical procedure appeared to be reflected by longer gaze durations, go-past times, and total reading times, but shorter first fixation durations. Perhaps these findings indicate that early lexical access allows readers to process word-frequency quickly and determines the extent to which later eye movement measures are deployed. For example, early eye movement measures may first indicate the frequency status of a word and may also indicate some early information on the length of a word, if the word is short or high-frequency, early eye movement measures may sufficiently process these word types without reliance on later eye movement measures. On the other hand, long and low-frequency words which may require a sub-lexical strategy will rely on longer late-stage eye movement measures to process the word efficiently. Further research using these eye movement measures is needed to confirm these interpretations.

Interestingly, these length and frequency interactions indicated a distinct time-course of word processing results compared to the native-English readers in *Experiment 2 (Chapter-2)*. For native-English readers, significant length by frequency interactions indicated that length effects were only found for low-frequency words but did not affect high-frequency words. Further, short words were not affected by frequency. However, for Spanish-English bilingual readers in Spanish, these interactions indicated that length effects were found for both low-frequency and high-frequency words. Although similar to the native-English readers there was only an effect of frequency for long words, but not short words. These findings support the weak version of the ODH Katz & Frost, 1992) which postulates that readers must adapt their reading strategies to meet the demands of the orthography being read. Specifically, in the strong version of the hypothesis, the ODH postulates that readers must adapt their reading strategies along two different routes that are dependent on the GPC consistency of the orthography being read. According to this account, word recognition in a consistent language is sufficient through sub-lexical GPC decoding strategies alone and is possible without use of a lexical processing strategy. However, in an inconsistent orthography, reading must be supported via a lexical procedure by using different kinds of lexical information (e.g., morphemic, semantic). On the other hand, the weak version of the ODH suggests that both lexical and sub-lexical procedures (or routes) are available to all readers, but the extent to which they are used to process words are dependent on the demands of the orthography being read. Thus, readers of consistent orthographies are more likely to succeed in reading by means of alphabetic decoding (i.e., sub-lexical) strategies than readers of inconsistent orthographies who must read most words by lexical strategies accessing the orthographic input and phonological output lexicons. Since it appears that Spanish-English bilingual readers in Spanish in the current study process frequency information in eye movements that reflect early lexical access before length information, a lexical strategy may be applied by default, until the later eye movement measures of lexical access determine length. Thus, the weak version of the ODH is supported based on these findings.

Similarly, Rau et al. (2014) also found both length and frequency effects in gaze durations for adult readers of German but found larger length effects for low-frequency compared to high-frequency words. The findings from the current experiment accord with this report, however even though the size of the length effect (i.e., the difference in processing time between long and short targets) in gaze durations was larger for low-frequency compared to high-frequency words (44.25 vs. 26.03), this did not reach significance. The difference between the current experiment and the study by Rau et al. (2014) may stem from the difference in sample sizes. Only 18 adult readers of German participated in the study by Rau et al. (2014) while the current experiment analysed eye movements from 38 participants. It is possible that there was more variability in a smaller sample size that disappeared with more participants. Another possibility may stem from the reading experience of the current sample. The current experiment analysed Spanish-English bilinguals who began to acquire English before the age of 5, while Rau et al. (2014) analysed monolingual readers. Thus, it is possible that their experience with learning English, may have affected their reading strategies when approaching their native language. The implications of this will be further explored in the next Chapter of the current thesis (Chapter-5).

4.3.5.2 Group comparisons for Word Level Measures between Experiment 2 (Native-English readers without dyslexia) and Experiment 6 (Bilingual Readers in Spanish)

Although the main effects of length and frequency for Spanish-English bilinguals reading in Spanish suggested a distinct time-course of word recognition compared to the native-English readers in *Experiment* 2 (Chapter-2) the effects of length and frequency in early and late eye movements of Spanish-English bilingual readers reading in Spanish were directly compared to those of native-English readers to test Hypothesis-3. This analysis allowed for an observation of whether the size of the length was larger and the size of the frequency effects were smaller for the Spanish-English bilinguals reading in Spanish compared to the native-English readers. This comparison was also driven by the ODH (Katz & Frost, 1992) which postulates that readers must adapt their reading strategies to meet the demands of the orthography being read.

Findings from the direct comparisons between Spanish-English bilinguals and native-English readers indicate that overall, the Spanish-English bilingual readers reading in Spanish had significantly shorter first fixation durations, gaze durations, and total reading times, but longer go-past times compared to native-English readers. Significant main effects of frequency were found for all the eye movement measures; however main effects of length were found for all eye movements except first fixation durations. This result was likely driven by the absence of a length effect for first fixation durations in Spanish-English bilingual readers. Frequency effects were indeed found to be smaller for readers of Spanish, compared to readers of English for all of the eye movement measures, although these effects did not reach statistical significance. Length effects also tended to be larger for readers of Spanish compared to readers of English, and in the case of gaze durations, this effect did reach statistical significance.

According to the Psycholinguistic Grain Size Theory (Zeigler & Goswami, 2005), readers of a consistent language may rely on sub-lexical decoding strategies because they are able to reliably process small grains of information from a word at a time (i.e., phonemes) to support successful reading. On the other hand, small grain processing is unreliable in inconsistent orthographies, and thus these readers must adapt reading strategies that process larger units at once (i.e., whole-words) through a lexical procedure. Thus, larger length effects would be expected for readers of consistent orthographies compared to readers of inconsistent orthographies who must use a larger grain size strategy which is not necessarily slowed by length. For the same reason, readers of consistent orthographies may use a small unit decoding strategy to process both high-frequency and low-frequency words at the same rate, whereas the larger unit strategy employed by readers of English is slowed by word frequency. Based on this account, readers of consistent orthographies are expected to be less sensitive to frequency effects compared to readers of inconsistent orthographies. Indeed, several studies have reported larger frequency effects (Landerl, Wimmer & Frith, 1997; Rau, Moll, Snowling & Landerl, 2015; Ziegler, et. al., 2001) and lexicality effects (Paulesu et al., 2000), but smaller length effects (Ellis & Hooper, 2001; Goswami, Gombert, & Fraca de Barrera, 1998, Rau, Moll, Snowling & Landerl, 2015; Ziegler, et. al., 2001) for readers of inconsistent orthographies compared to readers of consistent orthographies.

The findings from the current experiment however only partially support this account. Although frequency effects tended to be smaller for readers of Spanish compared to the readers of English, these effects did not reach significance. There was however a trend of larger length effects for readers of Spanish and in the case of gaze durations, these were significant. These findings support the notion that the bilingual readers of the consistent Spanish orthography tended to rely more on sub-lexical decoding strategies when reading in Spanish compared to readers of the inconsistent English orthography. This was apparent at all stages of lexical access according to the eye movement patterns. However, Spanish-English bilingual readers reading in Spanish were sensitive to both length and frequency effects indicating that they may have automatically applied a lexical process to read. Taken together, these results suggest that sub-lexical decoding strategies may not necessarily be the dominant reading strategy for adult readers of a consistent orthography, but there is greater reliance on this strategy compared to readers of an inconsistent orthography. These results also support the weaker version of the ODH (Katz & Frost, 1992), but not the strong version.

Somewhat in contrast, Rau et al. (2015) reported larger length effects for children but not adult readers of a consistent orthography compared to readers of an inconsistent orthography. For adults, however, frequency effects were indeed significantly larger for readers of inconsistent orthographies. Again, the difference in these results compared to the results of the current sample may have been a consequence of the bilingual reading experience from the participants in the current sample. Evidently, further research is needed, especially using eye tracking techniques to investigate reading strategies between readers of languages with varying orthographic consistency.

Reading Behaviour Between a Consistent and an Inconsistent Orthography

4.3.5.3 Correlations between Eye Movements measures and the Simple View of Reading Component Skills for Spanish-English Bilinguals in Spanish

Hypothesis-4 was tested by correlating the sentence-level eye movement measures with the reading abilities described in the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990) as well as vocabulary scores measured in *Experiment 5* in the current Chapter, in Spanish-English bilinguals reading in Spanish. Eye movement measures such as fixation count and fixation duration are considered to reflect decoding strategies (e.g., Rayner, Slattery, Drieghe, & Liversedge, 2011) and thus it was expected that these eye movements measured at the sentence-level would significantly correlate with the decoding scores measured in *Experiment 5*. Total reading time and regressions on the other hand should correlate with higher order language measures such as vocabulary, language comprehension and reading comprehension (e.g., Liversedge, Paterson, & Pickering, 1998; Rayner, 1998). This hypothesis was not supported, and no significant correlations were found.

These results contrast with those reported by Krieber et al. (2016) who reported that these skills have been linked to spatial eye movement parameters in readers of a consistent orthography (i.e., number of fixations, number of saccades, and saccade amplitudes). However, those results were from German adolescent readers, and in the current experiment participants were adult Spanish-English bilingual university students, thus, perhaps the same eye movements are not predictive of the same reading skills.

Following this, Hypothesis-5 was tested by correlating the word-level measures with the SVR component skills measured in *Experiment 5* in the current Chapter. It was expected that late eye movement measures of reading (i.e., go-past time and total reading time, thought to reflect higher order language skills) would be better predictors of reading comprehension abilities than early eye movement measures of reading in this sample given that language comprehension was a better predictor of reading comprehension in the current sample. This hypothesis was also not supported, and no significant correlations were found.

It might make sense that some of the temporal eye movement parameters (i.e., gaze durations, go-past times, fixation durations and total reading times) did not correlate with reading comprehension because other studies from consistent orthographies have also reported that these eye movements do not correlate with reading comprehension. For example, Krieber et al. (2016) reported that reading skills of German readers were not correlated with temporal eye movement measures (i.e., gaze duration, fixation duration, and total reading time) nor with the number of regressions made during any of the reading tasks. These results were interpreted to indicate that some reading skills are associated with eye movement measures regardless of orthography, but some eye movements, particularly temporal eye movements may vary with orthographic consistency.

The absence of significant correlation trends between online (eye movements) and offline (WMLS III subtests) reading measurements may indicate a dissociation of the offline and online reading tasks. Note that reading tasks were not identical in the current experiment, and thus results that compare the two may be difficult to interpret. In the current experiment, offline reading comprehension was measured using a cloze task where participants were instructed to provide missing words from texts of increasing difficulty. This is a different task from the one in which participants completed in the eye-tracking experiment where they read short simple sentences for meaning and answered a subsequent comprehension question. This specific task was chosen for the eye-tracking experiment because it better characterizes natural reading than a cloze task where participants have to pause to think of missing words. Thus, the reading results in the cloze task may be difficult to compare to the results from the eye-tracking. A second possibility for this result may have been the nature of the sentences. The sentences participants read were simple sentences and may not have been taxing enough to elicit a consistent pattern of strategy, especially late eye movement measures though to be associated with semantic and syntactic processing (i.e., go-past times and total reading times). Future research would benefit from using longer or semantically difficult texts such as newspapers or academic articles.

4.3.5.4 Limitations and Further Research

One major strength of this experiment is that it compared both online and offline measures of reading and extended previous literature by demonstrating the time-course of length and frequency effects in readers of a consistent orthography. One limitation of these results, however, is that the current sample consisted of Spanish-English bilingual participants who had also acquired English by the age of 8. Although their native language is Spanish, a consistent language, it is possible that this sample also developed reading strategies to assist in meeting the demands of the English orthography. Thus, the results of this experiment should be interpreted with caution. The following Chapter, Chapter-5, will further investigate the implications of the bilingual reading experience of the current sample.

Results also indicated that the eye movement measures observed in the current sample may have reflected abilities that were not captured in offline tasks, or that the offline tasks from the WMLS III did not accurately measure the skills they were intended to measure in this sample. Future research would benefit from including a battery of offline tasks to measure a wider variety of reading abilities and not just the ones included in the SVR.

As stated previously, the offline and online reading tasks were not identical, and thus may not be comparable. Future research would benefit from using several measures of reading comprehension and compare each of them with eye movement measures. It is worth noting however, that in the current experiment total reading time was highly correlated with nearly all of the other eye movement measures. Average reading time has been regarded as a measure of reading comprehension and used as such in previous studies (Rayner, Chace, Ashby, & Slattery, 2006).

4.3.5.5 Conclusion

The present experiment aimed to explore reading strategies as measured by eye movements in native-Spanish readers while they read whole sentences for meaning. The current experiment examined reading strategies as measured by both early and late eye movements and compared these strategies with native readers of English. Further, these eye movement measures were compared with the measured reading abilities of the components indicated in the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990) to determine whether developed reading abilities may be related to word reading strategies.

Findings from eye movements measured at the sentence-level indicated a pattern of shorter, but more frequent fixations and regressions, which may be indicative of a decoding strategy of reading (Rayner, 1998, Rayner, 2009; Liversedge, Paterson, & Pickering, 1998, Korneev, Matveevn, & Akhutina, 2020). Results from the word-level analyses indicated that all eye movements were sensitive to frequency effects, and nearly all the eye movement measures were sensitive to length effects, apart from first fixation durations. The time-course of these effects suggest that frequency information may be processed before length information and readers may automatically apply a lexical procedure based on early lexical information which minimised the need for longer processing in the late eye movement measures of lexical access which showed no frequency effect for short words. However, for in the case of low-frequency words, word length determined whether the lexical or sub-lexical procedure was employed such that the longer the word, the more likely the sub-lexical procedure would be used.

Comparisons with native-English readers indicated that frequency effects were smaller, and length effects were longer for native-Spanish readers, which was apparent in all eye movement measures. These important findings suggest that the native-Spanish readers rely to a greater extent on sub-lexical decoding strategies than native-English readers which likely results from the consistent GPCs in Spanish compared to English. These results also support the weaker version of the ODH (Katz & Frost, 1992), but not the strong version.

Overall, findings from the current experiment offer support to the ODH (Katz & Frost, 1992) and the PGST (Ziegler & Goswami, 2005). Results from eye movements suggest that skilled Spanish readers continue to use decoding strategies and small grain processing to support reading, although this may not necessarily be the dominant strategy. The current sample of readers in a consistent language also employed different strategies of reading compared to readers of inconsistent languages (Rayner, 1998; Rayner, 2009; Liversedge, Paterson, & Pickering, 1998, Korneev, Matveevn, & Akhutina, 2020). However, since eye movement measures did not significantly correlate with the offline measures of decoding, language comprehension, or reading comprehension, perhaps the offline measures used were not accurate indicators of these particular reading skills. If this is the case, it may be that the SVR cannot well account for differences in sentence reading strategies especially for skilled adults reading in a consistent orthography. Conversely, these results could imply that perhaps eye movements in consistent languages are not driven by the same skills as in inconsistent orthographies and instead reflect other reading skills that were not measured in the current experiment. Further research is needed to resolve such disparities.

The next Chapter of the current thesis will now focus on reading strategies of these same Spanish-English bilinguals, but this time as they read in their second language, English.

Chapter 5: The Simple View of Reading in a Second Language (Spanish-English Bilinguals Reading in English): A Behavioural Experiment and an Eye Movement Experiment

5.1 Chapter 5 Overview

Experiments 1-6 (Chapter-2 – Chapter-4) demonstrated reading strategies of inconsistent (English) and consistent (Spanish) orthographies. The question that remains is how would a reader who developed the skills to read a consistent orthography approach reading an inconsistent orthography? The current chapter investigated the reading strategies of native readers of Spanish as they read in their second language (English). The current chapter will also investigate how Spanish-English bilinguals approach their second language compared to their first (measured in Experiment 5 and 6 from Chapter-4) and compared with native English reading strategies (Experiment 1 and 2 from Chapter-2).

This chapter consists of two experiments, *Experiment 7*, a Behavioural Study where Spanish-English participants' language skills including language comprehension, vocabulary knowledge, decoding skills and reading comprehension were evaluated and *Experiment 8*, an eye-tracking experiment.

5.1.2 Ethics Statement

Both Experiments 7 and 8 were approved by The Institutional Ethical Review Board, University of Brunel London, Department of Psychology, United Kingdom (number IP - IRB/11942-LR-Aug/2018- 13812-2) (see Appendix 1). Written informed consent was obtained from each participant (see Appendix 2b), after participants read an information sheet (see Appendix 2a) about the purpose of the experiment and their right to as participants to withdraw at any point in time without giving a reason.

5.2 Experiment 7: The Simple View of Reading in a Second Language (Spanish-English bilinguals reading in English): A Behavioural Study

5.2.1 Introduction

The number of adults and children emigrating from their native country to an English-speaking nation has significantly increased in recent years. Further, research has determined that bilingualism is more prevalent than monolingualism globally (Grosjean, 2010). The Office for National Statistics (ONS) estimated that in 2011, 4.2 million people (7.7% of the UK population) reported that English was not their main language (Office for National Statistics, 2016). Further There are over 1.6 million learners (21%) with English as an Additional Language (EAL) in UK schools (Department of Education, 2020)

Of the languages other than English reported as a main language, around 120,000 (0.02%) people reported that their main language was Spanish. Similarly, in the United States, 75% of English learners are native Spanish speakers (Aud et al., 2010). While non-native families living in English-speaking countries may choose to speak their native language (L1) in their own homes, they must also learn to master a second language (L2) to effectively communicate in an English-speaking environment (e.g., schools, workplaces, etc.). Adult speakers of English as an additional language (EALs) must be proficient in English to find jobs to support their families and to engage with the community. Younger EALs attending secondary school or higher education in English must advance enough in their L2 to fully comprehend the taught content of the classroom and maintain a competitive learning pace with their monolingual peers. With the growing population of Spanish speakers and other non-native English speakers entering English-speaking countries, the processes of second language development and bilingual language processes is of growing concern.

Literacy is a critical step in L2 acquisition and is necessary for bilinguals learning an L2 to seek employment or to successfully embark on an education experience. Therefore, a key element to understanding bilingual language processes is to understand the processes of bilingual reading. Research in this area can offer important insights into the organization of multiple languages in the bilingual lexicon. These insights can in turn support the development of effective teaching strategies and assessments, diagnostic criteria for reading disabilities and interventions for EALs and bilingual readers. Currently, there is limited research for diagnosing and supporting EALs with literacy difficulties as most diagnostic assessments are standardised using only monolingual readers (e.g., Glutting, Adams, & Sheslow, 2000). Thus, there are practical benefits for educational purposes that come from this type of research. It is therefore important to develop a complete model of bilingual reading comprehension. To reach an understanding of L2 literacy acquisition, it is necessary to consider the structural differences between the varying writing systems of different languages.

As previously discussed, orthographies can differ in terms of consistency, and granularity (Wydell & Butterworth,1999; Katz & Frost, 1992; Zeigler & Goswami, 2005), and it has been well established that the processes monolinguals use to approach reading may differ between orthographies (Perfetti & Dunlap, 2008; Verhoeven & Perfetti, 2011; Seymour, Aro, & Erskine, 2003). Chapters 2- 4 in the current thesis also established that the processes involved in reading a consistent (Spanish) vs. an inconsistent (English) language differ in terms of the relative contribution of the component skills (e.g., decoding and language comprehension skills) described in the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990). Less is known however about the process by which bilingual readers approach their second language (L2) compared to their first language (L1), particularly when each language differs in orthographic grapheme-phoneme mappings. In this case, bilinguals must learn two different mapping systems for each of their languages. For example, Spanish-English bilinguals must learn that the phoneme /h/ maps onto the grapheme “h” in English, but maps onto the grapheme “j” in Spanish. Thus, reading strategies of a bilingual may result in a hybrid strategy that is influenced by both languages. There may be both benefits and consequences to this interaction of languages especially when investigating English L2 reading which is at the extreme end of the consistency continuum. Cross-language research with bilinguals and L2 learners is important in examining the extent of both the benefits and consequences of reading in an L2 as well as for determining whether prominent models of reading, such as the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990), are language specific or whether they can be used as a general framework to predict reading comprehension and diagnose reading disabilities among L2 readers. The current chapter will begin with an overview of the processes involved in reading in an L2 compared to reading in the L1, and will consider the role of transfer specifically between a consistent and an inconsistent orthography. Following this, will be a discussion of the SVR and its capacity to characterize reading in English as a second language for bilingual readers, and the impact of orthographic consistency.

5.2.1.1 Introduction to Reading Processes in a Second Language

At a foundational level, many processes employed in learning to read in an L1 may be similar to the processes required to learn to read in an L2. For instance, in alphabetic languages readers need to learn the grapheme-phoneme mappings in each language to learn to decode new words. There also appears to be some underlying core universal processes that may predict reading comprehension in both an L1 and L2. For example, early reading development in a L1 can predict successful reading development in an L2, and this trend appears to be stable over time (Lindsey, Manis, & Bailey, 2003; Relyea & Amendum, 2020; Riccio et al., 2001). In a recent large-scale longitudinal study (N = 312), Relyea and Amendum (2020) assessed Spanish-speaking bilingual children with varying levels of

English oral proficiency at six different time points from the fall and spring of kindergarten, and in the spring of Grade-1, 2, 3 and Grade-4. Spanish reading was assessed in kindergarten and several reading skills were measured in English using a reading achievement test including print familiarity, letter recognition, identification of initial and final word sounds, rhyming words, word recognition, vocabulary knowledge, and reading comprehension. These measures were combined to form a composite reading score and English and Spanish oral proficiency was also tested. Results deonstrated that Spanish reading skills measured in kindergarten were consistently related to English reading skills from kindergarten to Grade-4, and the students who performed better on Spanish reading tasks in kindergarten were more likely to have better English reading ability from kindergarten to Grade-4. Interestingly, at each point of testing, Spanish reading proficiency was better related to English reading than English oral proficiency, indicating that some underlying reading processes may be related across languages that may be independent of oral language processes.

In a similar study, Riccio et al. (2001) found that Spanish phonological awareness was predictive of reading fluency in both Spanish and English for children from Grade-1 to Grade-5. Specifically, Spanish phonological awareness accounted for 25% of the variance in reading fluency in Spanish and 20% of the variance in English reading fluency in Grade-1 and Grade-2. In contrast, for the older children in Grade-3, Grade-4, and Grade-5, phonological awareness only accounted for 17% of the variance in reading fluency in Spanish and 14% of the variance in English reading fluency. These results indicate that phonological awareness in the native language may play a role in supporting reading in both an L1 and an L2 and is particularly important early on in development. These findings also highlight the potential of early identification of difficulties in either an L1 or an L2 of at-risk bilingual children by measuring their L1 phonological abilities.

Indeed, there is a body of evidence to support the relationship between reading skills from an L1 and an L2. Some early arguments suggested that the basic reading skills in all languages share common underlying linguistic and cognitive processes (e.g., The Central Processing Hypothesis; Gholamain & Geva, 1999). According to this hypothesis, children with reading difficulties in one language will likely demonstrate similar problems in the other because of some common underlying deficit. However, evidence from behavioural dissociations between languages has determined that reading problems such as dyslexia may present in one language of a bilingual, but not in another. As previously discussed, Wydell and Butterwoth (1999) investigated the case of a student AS, an English-Japanese bilingual adolescent whose reading performance in Japanese kana and kanji at age 16 were as good as Japanese university students, but showed poor performance in English reading skills (especially on phonological tasks) compared to English and Japanese controls. Wydell and Kondo (2003) followed-up on AS, and found that his reading deficits, which were phonological in nature, persisted into adulthood and led to phonological dyslexia in English. This evidence suggests that reading deficits such as dyslexia may not be caused by some common underlying deficit but may in part be perpetuated by characteristics of the language or orthography.

Similarities and differences between reading in an L1 compared to an L2 have also been identified using imaging studies. For example, Nakada, Fujii and Kwee (2001) used functional magnetic resonance imaging (fMRI) to compare brain activation associated with reading in Japanese and in English (both as a first language and as a second language). Participants were either Japanese-English bilinguals or English-Japanese bilinguals. Both groups were balanced bilinguals and were highly literate in both their L1 and L2. Results demonstrated that when reading in their native languages, brain activation patterns were distinct between the native-Japanese and native-English readers. Specifically, the native-Japanese readers showed prominent activation in the areas flanking the posterior part of the inferior temporal sulcus in the left hemisphere, which the authors had previously found to be associated with kanji reading (e.g., Nakada et al., 1998; Nakada, 2000), this activation was exclusive to the native-Japanese readers. The native-English participants showed substantially greater activation in the lingual gyri in both hemispheres than the native-Japanese readers. However, it is important to note that some common activation patterns were found in the left fusiform gyrus. The authors interpreted these findings to indicate that reading acquisition in L1 may influence reading acquisition in the L2 even when the L1 and L2 have distinct coding structures and thus may process both of their languages within overlapping neural networks. However, when participants approached reading in their L2, results showed that they had maintained virtually the same activation patterns as they had used in their first language. These results suggest that there are separate neuroanatomic substrates of the cognitive processes involved in Japanese kanji reading compared to English reading, however there may be no difference in cognitive processes used between L1 and L2 reading.

Although this study by Nakada, Fujii and Kwee (2001) is informative, it is important to note that the readers in this sample did not begin formal education in the L2 until fourth and fifth Grade at around age 10 and 11 and thus acquired reading in their second language after the first had already been acquired and well established. Therefore, although the bilinguals were reported to be highly literate in both languages, they still may not read as efficiently as a monolingual. Therefore, using the same reading strategy from the L1 to approach the L2 as the brain activation patterns suggested, may hinder L2 reading. The authors did not compare reading strategies of the bilinguals to matched monolingual readers to quantify the extent to which reading strategies from the L1 to the L2 changed. The current Chapter of this thesis aims to bridge this gap by testing participants who began learning English at or before the age of 8 and thus may have been able to learn to adapt their reading strategies to each language. Further, a comparison was made between the bilinguals and age-matched monolingual readers in the current thesis Chapter to characterise the extent to which the L1 reading strategy changes to approach reading in an L2.

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Conversely, there is compelling neuroimaging evidence that proficient bilinguals may be able to adapt their reading strategies to the demands of the orthography despite some common processes between reading across different languages. This may be especially true when comparing L2 reading in English, which is on the extreme end of the orthographic consistent continuum, to L1 reading in a highly consistent language such as Spanish. Reading in Spanish is supported by a non-lexical reading strategy and readers can rely heavily on decoding and processing small grains of information at a time (i.e., individual letters) (Cuentos & Suarez-Coalla, 2009; Florit & Cain, 2011; Goswami, 2002; Seymour, Aro, & Erskine, 2003; Zeigler & Goswami, 2005). English, however, must be supported by both a lexical and non-lexical strategy using both small and large grains of information (i.e., rime or whole words) (Florit & Cain, 2011; Goswami, 2002; Seymour, Aro, & Erskine, 2003; Zeigler & Goswami, 2005).

As previously discussed, Paulesu et al. (2000) suggested that consistent orthographies such as Italian may involve more phonological processing than English. Their findings suggested that monolingual readers of English show greater activation than monolingual readers of Italian in the left posterior inferior temporal gyrus and the left anterior inferior frontal gyrus which they associated with greater reliance on semantic processing due to the inconsistent GPCs in English. In contrast, Italian readers showed greater activation of the left posterior superior temporal gyrus, which is associated with phonological processing. However, this leaves the question of whether bilingual readers will respond in the same way to two different orthographies.

In another imaging experiment, Jamal et al. (2012) investigated brain activation patterns using fMRI of early-exposed Spanish-English L2 proficient adult bilinguals reading in both Spanish, and English to test whether the same activity patterns were maintained across different orthographies. Results demonstrated that while classic areas associated with reading were activated in both languages (e.g., left-lateralized regions in the occipitotemporal, temporoparietal, and frontal cortices), there were differences in brain activation when the bilinguals read in English (their L2) than when they read in Spanish (L1). Specifically, activation of the left middle frontal gyrus extending into the superior frontal gyrus was greater while reading in English than in Spanish. These areas tend to be with phonological retrieval which is more demanding in English reading than in Spanish reading. Additionally, when participants read in their native Spanish, there was greater activation of left middle temporal gyrus, an area tends to be associated with retrieval of semantic knowledge. In contrast to the interpretations reported by Paulseu et al. (2000), these findings suggested that English, an inconsistent language, may require greater activation of frontal regions associated with phonological decoding whereas Spanish may allow for increased engagement with semantic processing through the left middle temporal areas. Such results indicate that proficient bilinguals can adjust strategies between their L1 and L2 to meet the needs of different orthographies at least within alphabetic languages (see also Brignoni-Perez, Jamal & Eden, 2020). Thus, although there are some common areas that are generally activated in reading in all languages, these results suggest that bilinguals adapt some different strategies when approaching reading in two different languages, providing support for the ODH (Katz & Frost, 1992). However, given the different conclusions reported by each of these studies, more research is needed to investigate the role of orthographic consistency in reading.

One reason for the differences found between the studies by Paulseu et al. (2000) and Jamal et al. (2012) may have been due to one sample being bilingual and the other being monolingual. Although it appears that bilinguals can adjust their reading strategies when reading in their L2, such reading processes may still be distinct from monolinguals reading the same language. For example, Kovelman, Baker, and Petitto (2008) used fMRI to investigate the brain activation patterns of highly proficient early-exposed Spanish-English bilingual adults reading in both Spanish (L1) and English (L2) compared to English monolinguals reading in English. Results demonstrated that the brain activation patterns of

English monolinguals were distinct from the patterns of the Spanish-English bilinguals as they read in English. Further, the Spanish-English bilinguals showed similar activation patterns between their L1 and L2.

There are two main reasons to expect that bilingual reading development might differ from monolingual reading development. The first, is that bilinguals are developing skills in two languages while monolinguals are only developing skills in one. The second reason is that bilinguals may transfer skills learned in one language to another. Such differences may come with advantages and disadvantages. For example, although word-level reading skills for L2 learners often reach the average range similar to monolingual readers (Lesaux & Siegel, 2003; Verhoeven, 2000), L2 learners may acquire reading comprehension in their second language at a slower rate than their monolingual peers (August, Carlo, Dressler, & Snow, 2005; Verhoeven, 1990), and may have a smaller vocabulary in either language compared to monolinguals (Bialystok, 1988; Rosenblum & Pinker, 1983). For instance, Verhoeven (1990) investigated the differences in reading acquisition processes between monolingual Dutch children learning to read in their native language and native Turkish children learning to read in Dutch as their L2. The Turkish children performed worse than their monolingual peers on tasks of word recognition and reading comprehension. On the other hand, bilinguals may command better control of executive functions and perform better than monolingual peers on executive control tasks (Barac & Bialystok 2012).

Cummins (2000; 1979) offered an Interdependence Hypothesis and proposed that prior reading knowledge and skills that are developed in a native language can influence development of reading abilities in a second language. The Interdependence Hypothesis argues that reading skills across languages are interdependent and that skills developed in an L1 will transfer and aid in supporting reading development in an L2. Cross-linguistic transfer was first introduced by Cummins in his Interdependence Hypothesis (1979) and refers to the tendency of bilingual readers to transfer skills they've learned from one language to another. Furthering this, based on results from their study, Proctor, August, Snow, and Barr (2010) hypothesized an Interdependence Continuum where the extent of the interdependence depends on the similarities between the two languages of a bilingual. For example, in their model, they found evidence of strong interdependence for alphabetic knowledge for Spanish-English bilinguals, a moderate interdependence for reading comprehension and a mild interdependence for Spanish oral language related to English reading comprehension. Similarly, Verhoeven (1990) suggested that there are two types of problems that may arise in second language reading – firstly interlingual learning problems where the native language interferes with reading in the second, and secondly, intralingual learning problems which stem from the structure of the languages (p.92).

To summarise, it appears as though some processes of L2 reading may be similar to L1 reading (e.g., language universal processes) such as some phonological processing, particularly if both the L1 and L2 are alphabetic languages (e.g., Relyea & Amendum, 2020; Riccio et al., 2001; Lindsey, Manis, & Bailey, 2003). However, there are also important distinctions (i.e., language specific processes) which may even be apparent at the neural level (e.g., Brignoni-Perez, Jamal & Eden, 2020; Jamal, Piche, Napoliello, Perfetti & Eden, 2012). These distinctions may partially stem from the unique developmental demands that two languages varying in orthographic consistency each place on bilingual readers and may also result from cross-linguistic transfer of skills from an L1 to an L2. Thus, an investigation of bilingual reading between languages of different orthographic structures should consider both the role of orthographic depth and the role of transfer. The following section will summarise some common findings in bilingual word-processing research and introduce cross-linguistic transfer and the role it may play in bilingual reading.

5.2.1.2 The Role of Cross-linguistic Transfer

Indeed, bilingual reading may be distinct from monolingual reading. This may occur because of the bi-directional influence of both an L1 and an L2 on developing reading skills and on the reading process. When approaching each language, bilinguals and L2 learners must attend to one language at a time while inhibiting the other (Bialystok, 2008; Dijkstra, Grainger, & Van Heuven, 1999). However, this control process is not without limitations, bilinguals may use knowledge acquired from reading in their L1 and apply that knowledge when reading in a L2.

Cognate Facilitation and Interlingual Homograph Inhibition Effects

There is a large body of evidence suggesting that reading skills in an L1 may significantly influence reading skills in an L2 (Deacon, Chen, Luo, & Ramirez, 2013; Koda, 2007; Lemhöfer et al., 2008; Pritchard & O'Hara, 2008; Relyea & Amendum, 2020; Royer & Carlo, 1991; Riccio et al., 2001; Verhoeven, 1990). This phenomenon, referred to as cross-linguistic transfer, may greatly impact comprehension, speed, and accuracy during reading in an L2. For example, research from lexical decision tasks often reports that bilinguals respond faster to cognates, which are translation equivalents with overlapping word form (e.g., *animal* and *actor,* have identical meanings in English and Spanish) than to control words (De Groot & Nas, 1991; Dijkstra, De Bruijn, Schriefers, & Brinke, 2000; Dijkstra, Grainger & Van Heuven, 1999; Libben & Titone, 2009). Called the *cognate facilitation effect,* this effect has even been found for cross-script trilingual readers who respond faster to images labelled by cognate names in all three languages than to controls (Poarch & van Hell, 2014).

In contrast, compared to controls, larger latencies are reported for interlingual homographs (i.e., words with identical orthographic forms but separate meaning across two languages (e.g., *sin* in English means an *immoral act*, but means *without* in Spanish). This phenomenon is termed the *interlingual homograph inhibition effect* (e.g., Dijkstra, Grainger & Van Heuven, 1999; Dijkstra, Timmermans, & Schriefers, 2000; Dijkstra, Van Jaarsveld, & Ten Brinke, 1998; Macizo, Bajo & Cruz Martín, 2010). Further, this effect seems to influence performance in both the L2 and the L1 (e.g., Dijkstra, Timmermans & Schriefers, 2000).

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Models of Bilingual Lexical Access

It is important to note that a core question across research on bilingual reading is the degree to which lexical access is *language-selective*, that is, only the target language is activated and there are two different lexicons for each language, or *language non-selective*, that is, all languages are initially co-activated with a shared lexicon (De Groot, Delmaar, & Lupker, 2000; Dijkstra & Van Heuven, 2002; Duyck, 2005; Nievas & Mari-Beffa, 2002; Simpson & Krueger, 1991). Evidence of cross-linguistic transfer is generally used as an indicator that lexical access is language non-selective, while an absence of transfer may indicate a language-selective process. Several models have been proposed to account for the cognate facilitation effect and the interlingual homograph inhibition effect. Two prominent models that have received attention across the literature proposed to account for findings from cross-language experiments include The Revised Hierarchical Model (RHM; Kroll & Stewart, 1994) and the Bilingual Interactive Activation Plus (BIA+; Dijkstra & van Heuven, 2002) models.

As an early model of bilingual lexical access, the RHM posits that there is a distinction between lexical information (i.e., word forms) and conceptual representations (i.e., meaning). At the lexical level, two lexicons are distinguished, one for the L1 and one for the L2 with translation equivalents connected through excitatory links. The links from the L1-L2 direction are stronger than from the L2-L1 direction. However, the two lexicons share a conceptual system where word meaning information is represented. The connection between the L1 lexical information and the semantic system are stronger than the links between the L2 lexical information and the semantic system.

However, the findings of a cognate facilitation effect and an interlingual homograph inhibition effect in both the L1 and the L2 (e.g., Dijkstra, Timmermans & Schriefers, 2000) tend to support the notion that all languages of a bilingual may be stored in the same lexicon and that access to the lexicon is non-selective meaning that all languages are available during retrieval. Most research seems to agree with this notion, and it has also formed the basis of well-supported models of bilingual language processing such as the Bilingual Interactive Activation (BIA; Dijkstra & Van Heuven, 1998) and Bilingual Interactive Activation Plus (BIA+) models (Dijkstra & Van Heuven, 2002). These models assume a shared lexicon with language non-selective lexical access and that languages are integrated at the semantic, orthographic, and phonological level. Thus, bilingual word recognition is affected by similarities at all three levels. Relevant to the current thesis on reading processes, this model assumes that orthographic whole-word lexical and phonological sub-lexical representations are activated simultaneously. Thus, both the lexical and sub-lexical route should be at the disposal of bilingual readers.

Indeed, cross-linguistic phonological priming effects have been found in semantic priming (Gollan, Forster, & Frost, 1997), picture–word interference (Kaushanskaya & Marian, 2004), and masked phonological priming (Brysbaert, Van Dyck, & Van de Poel, 1999; Van Wijnendaele & Brysbaert, 2002). These findings offer support for the language nonselective access hypothesis of bilingual phonological representation. For example, using the forward Duyck (2005) investigated whether the phonology of Dutch–English bilinguals was selectively or nonselectively accessed. Using pseudohomophones as stimuli, of one language (e.g., “ruch” as the pseudohomophone of “rug”, which means “back” in Dutch) to prime the target (e.g., “back”) of the other language. Phonological priming effects were found in both directions, from L1 to L2 and from L2 to L1, in the lexical decision task. This indicates that when the phonology of the target language was processed, the phonology of the nontarget language was also automatically activated.

In non-European alphabetic orthographies, similar findings have been reported. For example, in a masked forward priming paradigm investigating selective or nonselctive access in two different scripts (English vs Korean) Kim and Davis (2003) categorised the prime-target pair as either; cognates (sharing semantics and phonology), noncognates (semantics only), homophones (phonology only), and baseline (neither phonology nor semantics). In a lexical decision task and a semantic categorization task, a significant priming effect for cognate and noncognate translation primes however, homophone primes did not produce a significant priming effect. However, in a naming task, both cognate and homophone primes produced significant priming effects, but the noncognate translation primes did not. Taken together, these results indicate that phonology was activated nonselectively between English and Korean.

These findings may be intuitive across alphabetic languages where there is a high overlap between orthography and phonology. However, when considering logographic languages such as Chinese or Japanese Kanji where characters represent whole words rather than phonemes, there will be no orthographic overlap between these languages and alphabetic languages such as English. Zhou, Chen, Yang and Dunlap (2010) asked Chinese-English bilinguals to perform a naming task and a lexical decision task using either phonologically similar prime-target pairs or phonologically dissimilar prime-target pairs. Results demonstrated faster response times and better accuracy for the prime-target pairs in both tasks. These findings provide further support for the BIA+ model of bilingual processing, and language nonselective access to an integrated lexicon for bilingual phonological representations without the influence of orthography.

The current thesis focuses primarily on reading processes and the role of orthographic depth however, it is important to recognise the nature of bilingual lexical access and how it may influence distinct reading strategies for bilinguals compared to monolinguals..

Cross-linguistic Transfer of Reading Abilities

Reading research has demonstrated evidence of both cross-linguistic transfer of decoding and phonological abilities. For example, young native-Spanish speakers learning English have been found to transfer their phonological abilities from Spanish to successfully decode new words in English (Bialystok, Majumder, & Martin, 2003; Cisero & Royer, 1995; Dickinson, McCabe, Clark-Chiarelli & Wolf, 2004). Cisero and Royer (1995) tested bilingual native Spanish children with limited English proficiency and found that the ability to isolate initial sounds and performance in rhyming tasks in an L1 predicted the same ability in the second language. Similarly, Dickinson et al. (2004) found a reciprocal relationship between L1 and L2 phonological awareness skills such that L1 phonological awareness skills predicted L2 phonological awareness skills and vice versa in a sample of 4-year-old Spanish-English bilinguals.

Some findings further indicate that decoding skills may be more easily acquired in an L2. For example, Verhoeven (2000) found that second language learners of Dutch, were able to master word decoding and word-blending tasks as well as monolingual Dutch despite showing less efficient reading comprehension compared to the Dutch natives. Although Dutch is a consistent language where phonology is easily acquired, these findings suggest that L2 reading acquisition is distinct from L1 reading acquisition. Similarly, bilinguals, particularly with consistent native languages (i.e., Spanish, and Italian), are reported to have better phonological reading skills compared to English monolinguals and other English second language learners with inconsistent L1s (Bialystok, Luk, and Kwan 2005; D'Angiulli, Siegel, and Serra 2001). For instance, Bialystok, Majumder and Martin, (2003) reported that Spanish-English bilinguals, but not French-English bilinguals outperformed their English-monolingual peers in tasks of phoneme segmentation in English, suggesting a possible advantage in phonological abilities of readers from consistent languages. Such results make sense given that readers of consistent orthographies develop phonological decoding skills faster than readers of inconsistent orthographies (Aro and Wimmer 2003). These findings indicate that experience with a consistent orthography may provide bilinguals with a sensitivity to the phonology of a language which may facilitate acquisition of learning print-to-sound mappings in an L2, even if the L2 is more inconsistent than the first.

Lemhöfer et al. (2008) examined reading skills in three groups of bilinguals who's second languages were all English, but with first languages that had varying degrees of orthographic consistency; German, a consistent language, followed by Dutch, a less consistent orthography, and French, which is considered an inconsistent orthography (Seymour, Aro, & Erskine, 2003). Results revealed a large overlap in skills involved in word recognition in English across each bilingual group, but large differences when comparing the native English-speaking group. These results suggest that second language reading of English may be similar among readers from differing orthographies, but still different from monolingual processing of English.

According to the ODH, efficient reading requires bilinguals to adjust their reading strategies to meet the demands of a text's orthographic structure. If native readers of a consistent orthography attempt to read in an inconsistent orthography, they must begin to rely less on a sub-lexical strategy and instead deploy a lexical strategy to support efficient reading. If instead these readers continue using a sub-lexical strategy, reading will be slowed and less accurate. Similarly, native readers of inconsistent orthographies may read a more consistent L2 slowly and inefficiently if they use a lexical strategy when a sub-lexical strategy will suffice. Therefore, to efficiently read in an L2 comprising a different orthography from an L1, bilinguals must not transfer all L1 reading skills, but instead must adjust their strategies to support the demands of the orthography being read.

Based on the work discussed above, it may be expected that Spanish-English bilinguals would approach reading in their first language differently compared to reading in their second. Spanish texts should be processed via sub-lexical strategies using small grains of information while English texts must be read by drawing from larger grains of information and largely using a lexical strategy. However, Spanish-English bilinguals may approach reading in English based on their experience with reading in Spanish and thus may transfer some of their abilities to support English reading comprehension. It is unclear however, whether all readers can adjust their approach to different orthographies automatically and in the early stages of L2 learning, or whether it occurs deliberately and with reading experience in more proficient bilinguals. Thus, a question that remains is whether cross-linguistic transfer will persist into adulthood for bilinguals and to what extent. The overarching aim of the current studies in this Chapter was to address this question.

Further, while cross-linguistic relationships have consistently been reported for bilingual readers for phonological awareness, word identification, and decoding (e.g., Bialystok, Majumder, & Martin, 2003; Cisero & Royer, 1995; Dickinson, McCabe, Clark-Chiarelli & Wolf, 2004; Lindsey, Manis, & Bailey, 2003; Manis, Lindsey, & Bailey, 2004; Verhoeven, 1994), far less is known about the role of language comprehension. Although phonological and decoding skills are crucial to reading, current models of reading such as the SVR, also emphasize the importance of language comprehension skills. As Proctor et al. (2006) points out, language comprehension skills may be more nuanced than phonological decoding skills and therefore may be difficult to investigate. However, it is important that research continues to examine the nature of language comprehension skills and the role they may play in bilingual reading. Thus, the current study seeks to investigate the role of both phonological decoding and language comprehension skills within the context of a supported model of reading, the SVR. Since bilingual reading may be distinct from monolingual reading, models of reading such as the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990), may also function differently for a bilingual reader. The next section will outline research that has been undertaken using the SVR in bilingual readers and will discuss how the bi-directional influence of skills from both languages may play a role in explaining variance in reading comprehension in a second language.

It is important to note here that the current study investigated the role of transfer across alphabetic orthographies. Though there may be unique features to consider when readers are bilingual across two different scripts (e.g., see the script-dependent hypothesis; Geva & Siegel, 2000), it is outside of the scope of the current thesis to consider all these features.

5.2.1.3 The Simple View of Reading in a Second Language

The SVR has been extensively tested in native English readers (e.g., Hoover & Gough, 1990; Catts et al., 2003; Oakhill, Cain, & Bryant, 2003; Catts, Adlof, & Weismer, 2006). However, far fewer studies have tested the SVR in second language learners and bilinguals (though see e.g., Goodwin, August & Calderon, 2015; Nakamoto et al., 2008; Paige & Smith, 2017; Proctor et al., 2005, 2006; Verhoeven & Leeuwe, 2012). As discussed above, L2 reading involves an added level of complexity compared to reading in an L1. Factors such as cross-language transfer and the orthographic depth of each language must be considered. Thus, it is important and informative to test the SVR with these factors in mind to provide a clear understanding of L2 reading.

As previously noted, the SVR was originally tested in native English students enrolled in an English/Spanish bilingual reading instruction programme (Hoover & Gough, 1990). The sample of children in this study were native English speakers but learning to read in both a consistent (Spanish) and inconsistent (English) language through a bilingual education development program. To recap, the children were tested in English from kindergarten to Grade-4, and the authors found that the SVR multiplicative formula could account for significant variance in reading comprehension in English. Although the emphasis of the bilingual program was placed on English reading with the goal of transitioning to English reading only, the interpretation of these results should include a consideration of the unique set of reading strategies developed by this sample. However, the study only reported results from tests conducted in English and does not consider the skills developed from Spanish reading. A more comprehensive strategy, as was conducted in the current thesis, would be to compare results from the SVR in both languages of a bilingual.

Proctor et al. (2005) were among the first to construct a model of L2 reading using only L2 reading skills based on the SVR to serve as a baseline model for future studies. Proctor and colleagues measured L2 language comprehension abilities (vocabulary knowledge and listening comprehension) and decoding abilities (word reading and pseudoword reading) as predictors of L2 reading comprehension in a sample of native Spanish speakers learning English in Grade-4 (aged 10). As depicted in Figure 41, using a path analysis, the authors report that L2 pseudoword decoding and language comprehension could predict 65% of the variance in L2 reading comprehension with language comprehension playing the larger role. Real word reading did not significantly predict L2 reading comprehension, and although L2 pseudoword decoding was predictive of L2 reading comprehension, it was less predictive than listening comprehension and vocabulary knowledge. Further, vocabulary knowledge exerted both a direct and indirect effect on reading comprehension with the indirect effect mediated through its strong relationship with listening comprehension. The authors concluded that the SVR is indeed valuable in characterising L2 reading comprehension. Specifically, in L2 reading, it appears that with an adequate level of decoding (measured by pseudoword reading), L2 reading comprehension will further improve through vocabulary knowledge and listening comprehension skills.

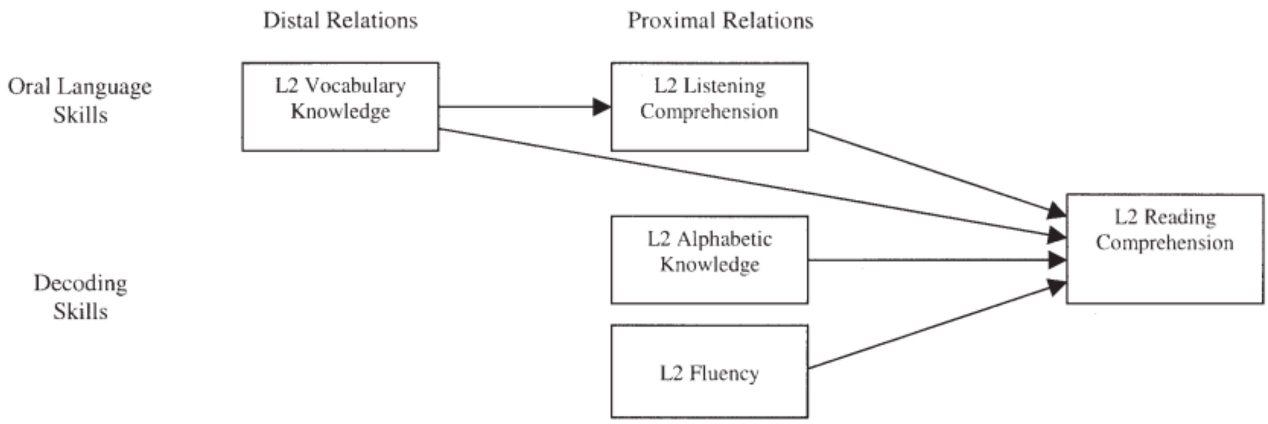

Figure 41. A model of English reading among Spanish-English bilinguals (Proctor et al., 2005)

Later, Paige and Smith (2017) fitted the same path analysis to Grade-5 native Indian-speaking English language learners and found similar results. Specifically, both decoding, and language comprehension accounted for 75% of the variance in reading comprehension, but language comprehension emerged as the stronger predictor. Vocabulary knowledge also exerted an indirect influence on reading comprehension when it was mediated by language comprehension.

The results from these studies are consistent with some English monolingual studies that report that the SVR accounts for significant variance in reading comprehension, and that for older readers, decoding exerts less of an influence on reading comprehension than language comprehension (e.g., see Garcia & Cain, 2014 for a meta-analysis). These findings suggest that the SVR can indeed model English L2 reading however, there may be distinct differences from monolingual English samples. Findings from studies that have tested the SVR in an L2 indicate that there may be unique contributions of decoding and language comprehension to reading comprehension compared to English monolingual readers (Goodwin, August & Claderon, 2015; Nakamoto, Lindsay & Manis, 2008; Proctor et al., 2005; 2006; Hoover & Gough, 1990). For example, Tilstra et al. (2009), also sampled Grade-4 readers, like Proctor et al. (2005), but who were native English speakers instead of native Spanish speakers. Findings showed that the contribution of both real word and nonword decoding to reading comprehension still accounted for 42% of variance in reading comprehension, which was higher than the proportion explained by language comprehension. These results are in stark contrast to Proctor et al. (2005) who found that L2 nonword decoding did predict L2 reading comprehension, but to a lesser extent than language comprehension, and L2 real word decoding did not significantly predict L2 reading at all. However, since Proctor et al. (2005) did not compare their sample with English monolingual peers, it is difficult to interpret how their results from native Spanish-speaking English learners may be similar or different from monolingual English reading.

Some researchers have included both L1 and L2 reading abilities as predictors of L2 reading to test the SVR as a model of second language reading comprehension. Proctor and colleagues (2006) later expanded upon their L2 only model and included analogue L1 reading skills (i.e., decoding both real words and nonwords, language comprehension, vocabulary knowledge, and reading comprehension) from the same sample of Grade-4 Spanish-English bilinguals. Results found that the L1 and L2 decoding measures (real word and nonword reading) were significantly correlated with one another, but L1 language comprehension and L1 vocabulary knowledge measures did not. Further, only L1 nonword reading (a decoding measure) significantly correlated with L2 reading comprehension in addition to L2 language comprehension and vocabulary. However, after controlling for L2 decoding and L2 language comprehension skills, results found that L1 decoding and L1 language comprehension did not explain any additional variance in L2 reading comprehension, but L1 vocabulary did significantly explain a small amount of additional variance (1%). An interesting observation was that L2 real word decoding also significantly correlated with L1 real word decoding, language comprehension, vocabulary, and reading comprehension. These relationships were further explored as interactions which showed only a significant cross-linguistic interaction between L1 vocabulary knowledge and L2 real word decoding, which explained an additional 1% of variation in L2 reading comprehension. These findings indicate a cross-linguistic relationship between L1 and L2 reading skills and highlight the potential benefit of including L1 reading skills when modelling L2 reading. However, as argued above, these results were not compared to monolingual peers and therefore this context isn't available in which to consider these results. The current study aimed to expand upon these findings and include a comparison with monolingual peers. This will also allow for an investigation of the ODH (Katz & Frost, 1992) by providing a direct comparison of readers from different orthographies.

It is important to point out that some authors have reported no evidence of cross-linguistic transfer with the SVR component measures. Goodwin, August, and Calderon (2015) examined how Grade-4 native Spanish speakers learning English, approached reading in their L1 compared to their L2. The sample of students were actively involved in a balanced literacy program that emphasized word and text level skills in both languages. Specifically, they measured phonological decoding and morphological awareness skills as predictors of reading comprehension and explored listening comprehension, word reading and vocabulary knowledge as mediators of that relationship in both Spanish and English. Using multivariate path analyses, the authors found that language comprehension, but not real word decoding significantly contributed to reading comprehension in both Spanish and English. Nonword decoding and vocabulary knowledge contributed to Spanish reading, but not English reading and morphological awareness contributed significantly to English reading only. Cross-linguistic analyses revealed no evidence of language transfer. None of the skills measured in Spanish significantly contributed to English reading in this sample, and no skills measured in English contributed to Spanish reading. The authors interpreted these results to indicate that bilinguals use different strategies when approaching each language with no evidence of transfer of these skills.

Further, although Proctor et al. (2006) reported evidence of transfer of vocabulary knowledge from the L1 to the L2, other studies have not always found the same effect. In a longitudinal investigation of low-achieving Spanish-Speaking children, Mancilla-Martinez and Lesaux (2010) reported that Spanish decoding and Spanish vocabulary did not contribute to English reading, resulting in an English only model explaining all the unique variance in English reading comprehension. Similarly, Nakomoto, Lindsay and Manis (2008) found that Spanish and English decoding, vocabulary, and language comprehension skills predicted Spanish and English reading comprehension in a within-language analysis for third-grade native Spanish-speaking English-language learners. However, cross-language comparisons showed that Spanish decoding vocabulary, and language comprehension skills did not significantly predict English reading comprehension skills nor did the English decoding, vocabulary and language comprehension skills significantly predict Spanish reading comprehension. Thus, there appears to be some inconsistencies across the literature regarding the role of transfer in L2 reading.

Taken together, there is evidence to suggest that L2 reading is distinct form monolingual reading. Part of this reason is that skills from the L1 may transfer to support reading in the L2. However, there remains some ambiguity in the literature as to the extent of cross-linguistic transfer. These inconsistencies warrant further investigation to better understand the processes of L2 reading to support EAL students and to create assessment and intervention materials for EAL readers with literacy difficulties.

5.2.2 Experiment 7: The Current Experiment

The findings from the previous experiments reported in this thesis raise the next theoretical question of how the SVR characterises reading comprehension in Spanish-English bilinguals reading in their L2, especially when it has a more inconsistent orthographic system than their L1. The goal of the current study was to consider the reading components described in the predictions of the SVR and to determine the extent to which decoding and language comprehension abilities drive the strategies involved in skilled reading in English for bilingual readers of both a consistent (Spanish) and inconsistent (English) orthography. One potential use of the SVR could be to help identify second language reading disabilities. A particularly important consideration is whether the SVR could detect reading disabilities versus general language fluency difficulties in bilingual readers. Bilingual children reading in English as a second language may be assumed to be performing poorly in their L2 when, in fact, they are struggling with a reading disability. For example, learners of a second language might perform well in speaking and listening tasks, but poorly in L2 reading tasks. For these reasons, in *Experiment 7,* the current experiment, English reading abilities were measured in a sample of college aged native Spanish speaking Spanish-English bilingual readers without reading impairments. The measures included the language components such as decoding, language comprehension and reading comprehension from the SVR (Gough & Tunmer, 1986), as well as vocabulary knowledge (from Turner & Chapman, 2012).

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The current study aimed to further test the SVR in the same sample of Spanish readers from *Experiment 5* (Chapter-4), but this time in their second language (English), while also investigating the role of L1 reading abilities. The results from the current study were subsequently compared to results from both *Experiment 1* (Chapter-2) and *Experiment 5* (Chapter-4) to provide a comprehensive account of how the SVR model and the component skills interact in a sample of monolinguals compared to bilinguals reading in their first and second language. Results from this study were considered within the framework of the ODH (Katz & Frost, 1992) and implications for instruction and intervention will be discussed.

As was conducted in *Experiment 1 (Chapter-2) 3 (Chapter-3) and 5 (Chapter-4)*, the current experiment used subtests from the Woodcock-Munoz Language Survey III (Woodcock, Alcarado, & Ruef, 2017) meant to measure each of these abilities (i.e., language comprehension, decoding skills, reading comprehension and vocabulary knowledge).

5.2.2.1 Hypotheses

The current experiment aimed to investigate the following hypotheses:

1. Similar to results from English native speakers in *Experiment 1* (Chapter-2), It was predicted that both decoding and language comprehension should be highly correlated with reading comprehension, but less correlated with one another as the SVR states that these components are independent from each other. It was also predicted that each variable should be able to account for some of the variance in reading comprehension on their own, but that their combination should account for greater variance.

2. It was also predicted that the SVR component variables should be able to account for a significant proportion of variance in English reading comprehension for the sample of Spanish-English bilinguals. Since both the additive model (RC = D + LC) and the multiplicative model (RC = D x LC) were adequate at accounting for variance in

reading comprehension for native-English readers in *Experiment 1* (Chapter-2), the same was expected in the current experiment.

3. Since bilingual reading processes differ from monolingual readers, and there is strong evidence that the first language influences the second, it was expected that the proportion of variance accounted for by the decoding and language comprehension components would differ from the proportions in *Experiment 1* (Chapter-2) and the proportions reported in *Experiment 5* (Chapter-4) that accounted for Spanish reading comprehension for the same sample of Spanish English bilinguals. Specifically, it was expected that decoding would account for a higher proportion of variance for English reading comprehension than it did for Spanish reading comprehension in *Experiment 5* (Chapter-4) for the Spanish-English bilinguals given that English is a more inconsistent language and demands an ongoing contribution of decoding skills. Decoding should also account for a higher proportion of variance in English reading comprehension compared to English monolingual readers given that most reading development for this sample was in a transparent language where decoding skills reach near ceiling levels of mastery. However, similar to English monolingual readers, Language comprehension should still account for more variance in reading comprehension than decoding since the bilinguals learned English before the age of 8 and read at a proficient level.
4. Given the results from *Experiment 1* (Chapter-2) where vocabulary contributed unique variance to reading comprehension above and beyond decoding and language comprehension, as well as reports that vocabulary knowledge has been an influential addition to the SVR model in previous research (Binder et al., 2017; Braze et al., 2007; Vellutino et al., 2007; Ouellette & Beers 2010; Tunmer & Chapman, 2012), it was expected that English vocabulary knowledge would explain additional

variance in English reading comprehension after controlling for decoding and language comprehension.

5. Finally, given the extensive evidence of cross-linguistic transfer, it was expected that each of the Spanish reading abilities previously measured in *Experiment* 5 (Chapter-4) (Spanish decoding, Spanish language comprehension, Spanish vocabulary knowledge, and Spanish reading comprehension) would demonstrate a relationship with the English reading abilities measured in the current experiment either directly, or indirectly through L2 reading skills.

5.2.3 Methods

5.2.3.1 Participants

Participants were the same Spanish-English bilingual readers who participated in *Experiment 5* and *6* (Chapter-4), who agreed to participate in a second experiment for the current experiment. To recap, participants were 38 Spanish-English bilingual readers aged 18-30 (35 females M_{age} = 24.57, SD = 3.67), who were recruited from the University of Granada in Granada, Spain. Participants were recruited via flyers and were awarded 10€ for participation. All participants had normal or corrected-to-normal vision and were native Spanish speakers who reported that they began reading English before the age of 8. Though participants did not directly indicate their type of English instruction, the typical instruction system in Granada, and in most parts of Spain involves English-only instruction (i.e., the language of the classroom is English) until age 12 and then bilingual instruction with both Spanish and English after the age of 12.

5.2.3.2 Measures and Materials

The same subtests from *Experiment 1* from the *Woodcock-Muñoz Language Survey III* (WMLS III; Woodcock, Alcarado, & Ruef, 2017) were used to assess participants' language skills, which are vocabulary knowledge - Picture Vocabulary, decoding skills - Letter-Word

Identification, language comprehension - Verbal Analogies and reading comprehension - Passage Comprehension.

5.2.3.3 Procedure

The procedure was identical to that detailed in *Experiment 5* (Chapter-4) except that all materials were administered in English.

5.2.4 Results

5.2.4.1 Descriptive Statistics for Spanish-English Bilinguals in English

The results from the demographics and language history questionnaire are tabulated below in Table 23 (Chapter-4).

Means raw scores and standard deviations for each reading ability measure are tabulated in Table 24 (Chapter-4).

5.2.4.2 Comparisons between English Monolingual Scores and Spanish-English Bilinguals in English on the WMLS III

Since the current sample of Spanish-English bilingual readers completed the exact same WMLS III ability measures, their scores were compared to the English monolingual readers form *Experiment 1* (Chapter-2) using a set of independent T-Tests with Bonferroni corrected alphas of .013 to measure whether the Spanish-English bilinguals scored significantly differently to the English monolinguals. This analysis was only computed for the English measures in the current experiment. Although the Spanish measures were analogous and tapped into the same skills, the Spanish measures were not the same and some did not have the same number of items and thus cannot be directly compared.

Language Comprehension There was a significant difference in English language comprehension scores between native English monolingual readers and Spanish-English bilinguals reading in English $t(84) = 3.24$, $p < .01$. Native English readers scored higher on language comprehension skills (*M* = 28.87, *SD* = 3.59) compared to Spanish-English bilinguals (*M* = 26.06, *SD* = 4.40).

Decoding Skills There was a significant difference in English decoding scores between native English monolingual readers and Spanish-English bilinguals reading in English $t(84) = 6.97$, $p < .001$. Native English readers scored higher on the measure of decoding (*M* = 70.19, *SD* = 2.93) compared to Spanish-English bilinguals (*M* = 64.85, *SD* = 4.18).

Vocabulary Knowledge There was a significant difference in English vocabulary knowledge scores between native English monolingual readers and Spanish-English bilinguals reading in English $t(84) = 8.02$, $p < .001$. Native English readers scored higher on the measure of vocabulary (*M* = 42.10, *SD* = 3.40) compared to Spanish-English bilinguals (*M* = 34.18, *SD* = 5.90).

Reading Comprehension There was a significant difference in English reading comprehension scores between native English monolingual readers and Spanish-English bilinguals reading in English $t(84) = 5.46$, $p < .001$. Native English readers scored higher on the measure of reading comprehension (*M* = 43.63, *SD* = 3.39) compared to Spanish-English bilinguals (*M* = 38.71, *SD* = 4.99).

5.2.4.3 Correlation Analysis for Spanish-English Bilinguals in English

The scores from the WMLS III (Woodcock, Alcarado, & Ruef, 2017) were correlated with each other again with Bonferroni corrected alphas of .013. As shown in Table 32, there was a significant positive correlation between language comprehension scores and vocabulary knowledge scores, $r(38) = .65$, $p < .001$, decoding scores $r(38) = .69$, $p < .001$, and reading comprehension scores $r(38) = .78$, $p < .001$. There was also a significant positive correlation between vocabulary knowledge scores and decoding scores $r(38) = .47$, $p < .001$, and reading comprehension scores $r(38) = .60$, $p < .001$. Finally, there was a significant positive correlation between decoding scores and reading comprehension scores $r(34) = .73$, $p < .001$.

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Table 32. Correlations of Spanish-English Bilingual Language Abilities in English.

	Language Comprehension	Vocabulary Knowledge	Decoding
Vocabulary Knowledge	.65***		
Decoding	.69***	.47***	
Reading Comprehension	.78***	.60***	.73***

Notes: correlation is significant at the $p < .001$***

These correlations will be explored as regressions in the following sections especially with reference to the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990). Since these measures were highly correlated with one another (see Table 34), we also tested for multicollinearity using the variance inflation factor (VIF). A high degree of multicollinearity poses a problem to the regression because it increases the variance of the regression coefficients, making them unstable. A VIF over 5 indicates high correlation and is generally suggested as a cut-off point (e.g., Simon, 2009). All variables had VIFs < 5, indicating that collinearity was not a problem.

5.2.4.4 Regression Analysis for Spanish-English Bilinguals in English

Simple linear regressions were calculated to see which of the component skills, i.e., decoding skills or language comprehension skills predicted reading comprehension separately. As shown in Figure 42, English decoding scores significantly predicted English reading comprehension $t(38) = 6.03$, $p < .001$, $R^2 = 0.53$ and explained 53.2% of variance for Spanish-English bilinguals reading in English. To be exact, the model predicted that reading comprehension scores would increase by 0.87 points for each additional decoding score point.

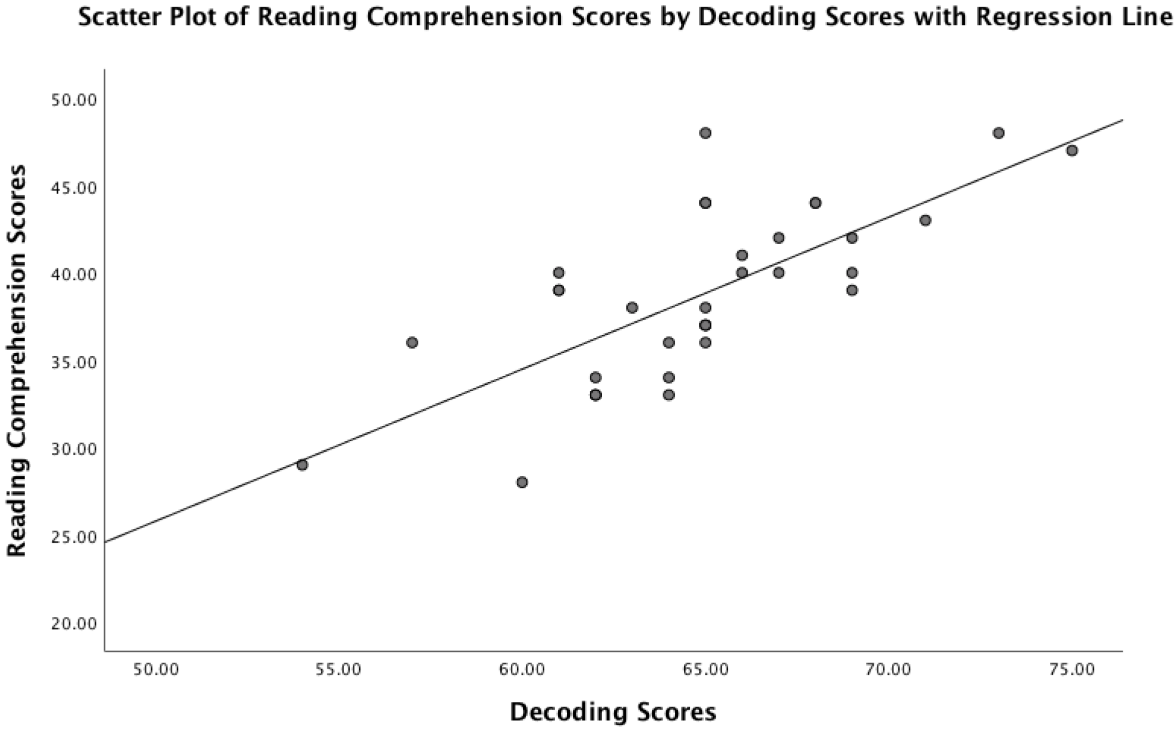

Figure 42. Correlation between English Decoding Scores and English Reading Comprehension Scores for Spanish-English Bilinguals

As seen in Figure 43, Language comprehension was also a significant predictor of reading comprehension for Spanish-English bilingual readers $t(38) = 7.03$, $p < .001$. Language comprehension explained 60.7% of the variance in reading comprehension. To be exact, the model predicted that reading comprehension scores would increase by 0.88 points for each additional point.

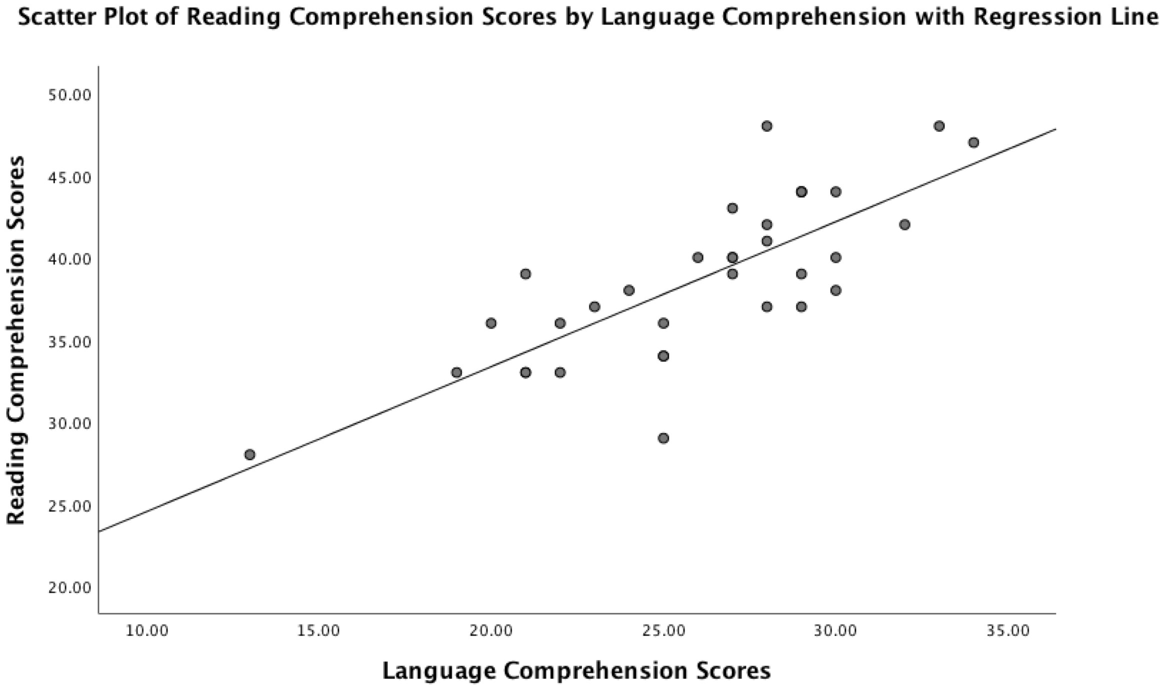

Figure 43. Correlation between English Language Comprehension Scores and Reading Comprehension Scores for Spanish-English Bilinguals

Next, the pattern of correlations among each reading ability (decoding and language comprehension) was examined using hierarchical regressions to predict reading comprehension.

A hierarchical regression examined whether language comprehension and decoding predicted reading comprehension better than decoding alone (Table 33). In Model 1, the overall model was significant $F(1,37) = 36.32$, $p < .001$, $R^2 = 0.53$, such that decoding explained 53% of the variation in reading comprehension. Adding language comprehension to the model did produce a significant improvement on Model 1, $\Delta F(1,37) = 14.08$, $p < .001$, such that overall Model 2 was significant $F(2,36) = 32.63$, $p = .001$, $R^2 = 0.68$, and now explained 68% of the variation in reading comprehension ($\Delta R^2 = 15\%$). As shown in Table 35, language comprehension ($\beta = .53$) emerged as a stronger predictor of reading comprehension than decoding ($\beta = .37$).

Table 33. Beta Weights in Hierarchical Regression Model Predicting English Reading Comprehension with the SVR Component Skills for Spanish-English Bilinguals

		B (SE)	**β**	***t***	***p***
Model 1	Constant	17.74 (9.38)			
	Decoding	.87 (.14)	.73	6.03	.000
Model 2*	Constant	5.27 (8.58)			
	Decoding	.44 (.17)	.37	2.62	.014
	Language Comprehension	.60 (.16)	.53	3.75	.001

* indicates significant model improvement

5.2.4.5 Simple View of Reading for Spanish-English Bilinguals in English

The SVR formula (Gough & Tunmer, 1986; Hoover & Gough, 1990) was then tested on these data. The SVR postulates that the multiplicative combination of decoding and language comprehension will be a better predictor of reading comprehension than the linear combination of decoding and language comprehension.

First, the product term of decoding and language comprehension was computed, and a subsequent linear regression was conducted to test the (Decoding x Language Comprehension) product model as a predictor of reading comprehension. As shown in Figure 44, the regression revealed that the product model explained 67% of the variance for Spanish-English Bilinguals $t(38) = 8.03$ $p < .01$, $R^2 = .67$.

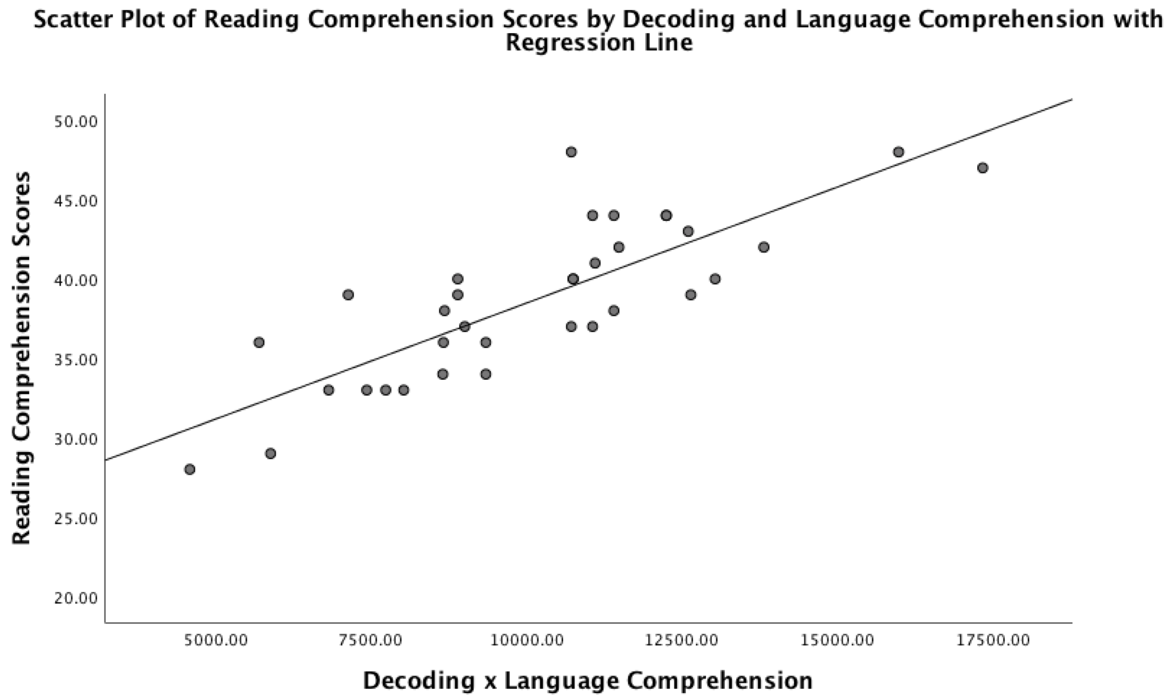

Figure 44. Correlation between the Product of English Decoding and English Language Comprehension Scores and English Reading Comprehension Scores for Spanish-English Bilinguals

Next, multiple regressions examined whether the product model would predict unique variance over the additive model of the SVR (Gough & Tunmer, 1986) these regressions are tabulated in Table 34. The additive model was significant $F(2,36) = 32.63$, $p = .001$, $R^2 = 0.68$, and explained 68% of the variation in reading comprehension. The addition of the product term to the model yielded an overall significant model 2, $F(3,36) = 21.08$, $p < .001$, $R^2 = .68$, but accounted for no additional variance, and this increase was not significant ($p = .860$). The same results were found when conducted in reverse, and the addition of the linear term accounted for a non-significant ($p = .737$) additional .007% of the variance in reading comprehension.

Table 34. Beta Weights in Multiple Regression Model Predicting English Reading Comprehension for Spanish-English Bilinguals

	B (SE)	**β**	***t***	***p***

Model 1	Constant	5.27 (8.58)			
	Decoding	.44 (.17)	.37	2.62	.014
	Language Comprehension	.60 (.16)	.53	3.75	.001
Model 2	Constant	3.41 (49.58)			
	Decoding	.30 (.79)	.25	.38	.709
	Language Comprehension	.30 (1.74)	.26	.17	.869
	Product (D x LC)	.005 (.03)	.36	.18	.860
Model 1	Constant	19.90 (2.38)			
	Product (D x LC)	.01 (.001)	.655	6.12	.000
Model 2	Constant	3.41 (49.58)			
	Product (D x LC)	.005 (.03)	.36	.18	.860
	Decoding	.30 (.79)	.25	.38	.709
	Language Comprehension	.30 (1.74)	.26	.17	.869

* indicates significant model improvement

5.2.4.6 Vocabulary Knowledge for Spanish-English Bilinguals in English

A simple linear regression was calculated to see whether vocabulary knowledge predicted reading comprehension on its own. As shown in Figure 45, vocabulary knowledge was also a significant predictor of reading comprehension $t(38) = 4.24$, $p < .001$, $R^2 = 0.36$. To be exact, the model accounted for 36% of the variance in reading comprehension.

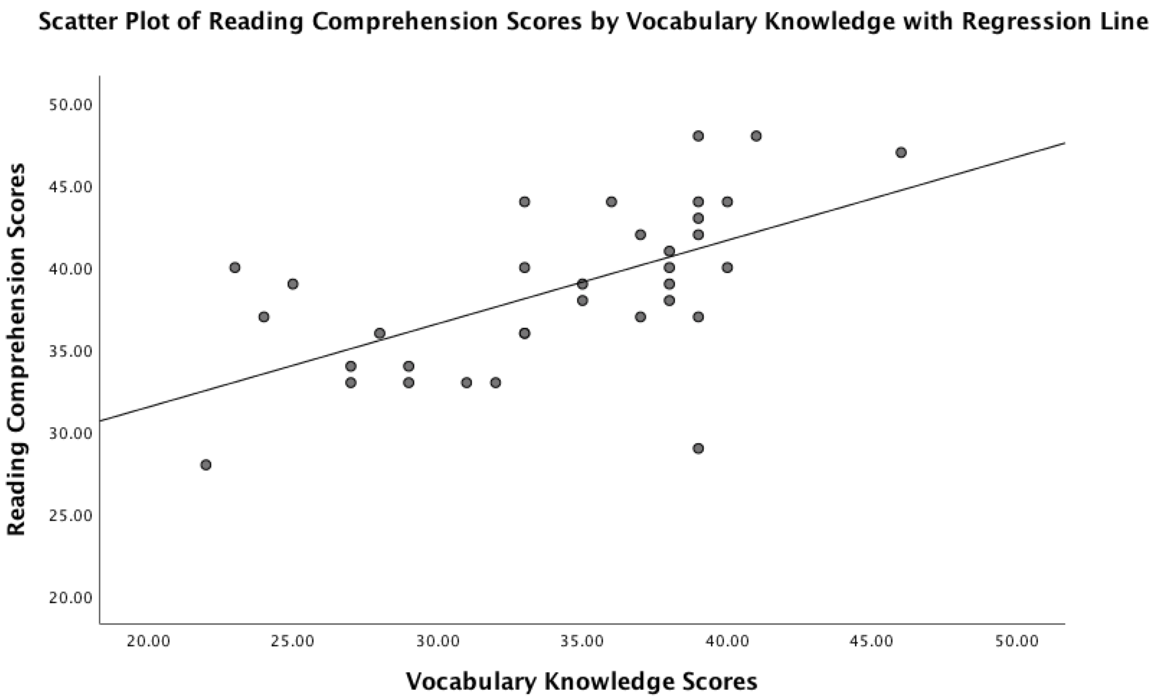

Figure 45. Correlation between English Vocabulary Knowledge Scores and English Reading Comprehension Scores for Spanish-English Bilinguals

Next, vocabulary knowledge was added to the previous hierarchical models which included decoding and language comprehension. Vocabulary knowledge was added as a third step was included to test whether this skill would predict reading comprehension scores above and beyond decoding and language comprehension scores (Table 35). Model 3 did not significantly improve upon Model 2, $\Delta F(1,37) = 1.28$, $p = .266$, though Model 3 was significant overall $F(3,35) = 22.38$, $p < .001$, $R^2 = 0.69$, and explained 69% of the variance in reading comprehension ($\Delta R^2 = 1\%$). As shown in Table 37, language comprehension (β = .43) emerged as the strongest predictor of reading comprehension, followed by decoding (β = .36) and vocabulary knowledge (β = .15), which was not a significant predictor in this model, $p =$ .266.

Table 35. Beta Weights in Hierarchical Regression Model Predicting English Reading Comprehension with Three Reading Abilities for Spanish-English Bilinguals

		B (SE)	**β**	*t*	*p*
Model 1	Constant	17.74 (9.38)			
	Decoding	.87 (.14)	.73	6.03	.000
Model 2*	Constant	5.27 (8.58)			
	Decoding	.44 (.17)	.37	2.62	.014
	Language Comprehension	.60 (.16)	.53	3.75	.001
Model 3	Constant	6.33 (8.59)			
	Decoding	.43 (.17)	.36	2.58	.015
	Language Comprehension	.49 (.18)	.43	2.69	.012
	Vocabulary Knowledge	.13 (.11)	.15	1.13	.266

* indicates significant model improvement

These same steps were then done in reverse, and a hierarchical regression was performed examining whether vocabulary knowledge and language comprehension predicted reading comprehension better than vocabulary knowledge alone (Table 38). In Model 1, the overall model was significant $F(1,37) = 18.01$, $p < .001$, $R^2 = 0.36$, such that vocabulary knowledge explained 36% of the variation in reading comprehension. Adding language comprehension to the model produced a significant improvement on Model 1, $\Delta F(1,37) = 21.61$, $p < .001$, such that overall Model 2 was significant $F(2,36) = 25.60$, $p < .001$, $R^2 = 0.62$, and now explained 62% of the variation in reading comprehension ($\Delta R^2 = 26\%$). As shown in Table 36, language comprehension (β = .67) emerged as a stronger predictor of reading comprehension than vocabulary knowledge (β = .16), which was not a significant predictor.

Table 36. Beta Weights in Reverse Hierarchical Regression Model Predicting English Reading Comprehension with Three Reading Abilities for Spanish-English Bilinguals

		B (SE)	**β**	*t*	*p*

Model 1	Constant	21.37 (4.14)			
	Vocabulary Knowledge	.51 (.12)	.60	4.24	.000
Model 2*	Constant	14.08 (3.59)			
	Language Comprehension	.76 (.16)	.67	4.65	.000
	Vocabulary Knowledge	.14 (.12)	.17	1.15	.258
Model 3	Constant	-6.33 (8.59)			
	Language Comprehension	.49 (.18)	.43	2.69	.012
	Vocabulary Knowledge	.127 (.11)	.15	1.13	.266
	Decoding	.43 (.17)	.36	2.56	.015

* indicates significant model improvement

Finally, the third step tested whether decoding scores would predict reading comprehension scores above and beyond language comprehension and vocabulary knowledge scores (Table 36). Model 3 did significantly improve upon Model 2, $\Delta F(1,37) = 6.63$, $p = .015$, and as seen above, this model was significant overall $F(3,35) = 22.38$, $p < .001$, $R^2 = 0.69$, and explained 69% of the variance in reading comprehension with both decoding and language comprehension emerging as significant predictors.

5.2.4.7 Relationship between English reading abilities and Spanish Reading Abilities (Chapter-3) and Cross-linguistic Transfer for Spanish-English Bilingual Readers

To determine whether there is a relationship between English and Spanish reading skills for Spanish-English bilinguals, correlations were calculated across scores from the WMLS III with Bonferroni corrected alphas of 0.003. Table 37 shows that all Spanish skills were correlated with English reading skills, but that Spanish language comprehension had the strongest relationship with the greatest magnitude.

Table 37. Correlations of Spanish-English Bilingual Language Abilities in English and Spanish.

	Spanish Language Comprehension	Spanish Decoding	Spanish Vocabulary Knowledge	Spanish Reading Comprehension
English Language Comprehension	.41*	.53**	.20	.40*
English Decoding	.37*	.35*	.17	.29
English Vocabulary Knowledge	.42*	.23	.37*	.26
English Reading Comprehension	.54***	.39*	.36*	.44**

Notes $p < .05$*, $p < .01$**, $p < .001$***

Next, to explore the effects of cross-linguistic transfer, multivariate path analyses using the Lavaan (0.6-7) package in R (Rosseel, 2012) were computed on these data to explore mediators and model fit. Path analysis is similar to structural equation modelling except all variables are single observed indicators rather than consisting of latent variables (Keith, 2005). This type of analysis allows for both direct and indirect contribution of predictors to outcomes. A model was fit with English reading comprehension as the outcome variable. The initial model included all the L2 reading abilities as well as all the L1 reading abilities to predict L2 reading comprehension, however this model proved not be an adequate fit for the data x^2 (N = 38) = 0.01, $p < .001$, SRMR = .26, CFI = .71). The best fit model for English reading comprehension included all English and Spanish variables except for Spanish vocabulary and Spanish reading comprehension.

As depicted in Figure 46, a model was fit where Spanish decoding and language comprehension predicted English reading comprehension either directly or indirectly through their contributions to English vocabulary, decoding, and language comprehension. The model x^2 (N = 38) = 0.40, p = .526, showed excellent fit to the data as indicated by confirmatory fit index [CFI] = 1.00 and the standardized root mean squared residual [SRMR] = 0.03) according to the suggestions of fit by Hu and Bentler (1998, 1999) and accounted for

72% of the variance in reading comprehension ($R^2 = 0.72$). As demonstrated in Figure 46, English language comprehension (*b* = 0.49, *SE* = 0.18, *p* < .01), English decoding (*b* = 0.39, *SE* = 0.15, *p* < .01), and Spanish language comprehension (*b* = 0.51, *SE* = 0.25, *p* < .01) made significant direct contributions to English reading comprehension.

Spanish decoding did not make any significant direct contributions to English reading comprehension but did make significant indirect contributions via English language comprehension (*b* = 1.29, *SE* = 0.54, *p* < .05) and also made significant total contributions (*b* = 1.60, *SE* = 1.28, *p* < .01) despite a nonsignificant indirect contribution through English decoding. Therefore, it appears that the relation between Spanish decoding and English reading comprehension is fully mediated by English language comprehension skills.

In contrast, Spanish Language comprehension made a significant direct contribution to English reading comprehension (*b* = 0.51, *SE* = 0.25, *p* < .01) and a significant total contribution to English reading comprehension (*b* = 1.09, *SE* = 0.30, *p* < .001). One significant indirect path was found between Spanish language comprehension and English reading comprehension through the combined path of both English decoding and English language comprehension (*b* = 0.49, *SE* = 0.22, *p* < .05), but not through either of these English mediators separately.

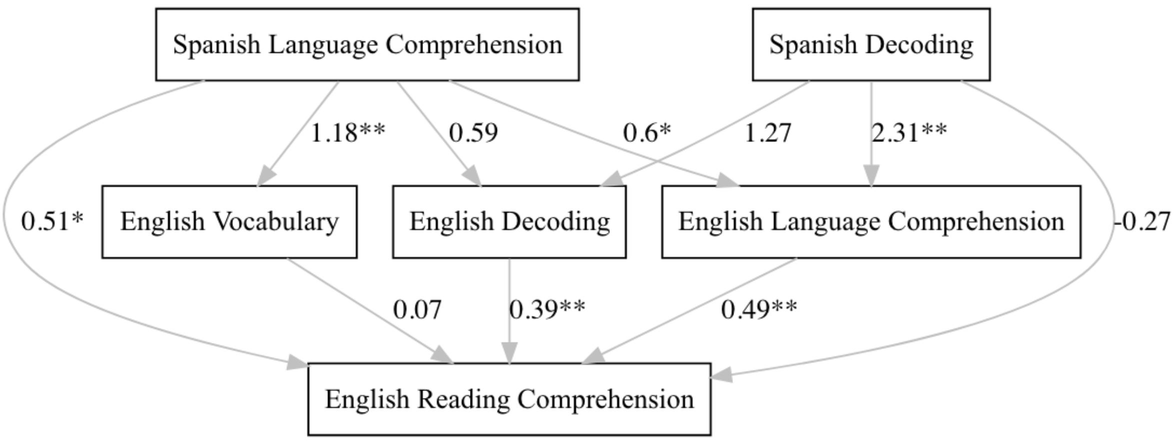

*Figure 46. English Reading Comprehension Model for Spanish-English Bilinguals with Standardized Regression Output * p <.05, ** p < .01, *** p < .001*

5.2.5 Discussion

The aim of *Experiment 7* was to measure the extent to which the language components (decoding, language comprehension and reading comprehension) described in the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990) may contribute to variance in reading comprehension in a sample of Spanish-English bilingual readers reading in their second language (English), which has a less consistent orthography than their native language. We also investigated whether skills measured in the L1 transferred to support reading in the L2. Of further interest, was to investigate whether vocabulary knowledge played an additional role in explaining variance in reading comprehension above and beyond the component skills from the SVR.

Results demonstrated that the Spanish-English bilinguals performed significantly worse than the native-English readers from *Experiment 1* (Chapter-2) on each of the subtests. However, according to the *Woodcock-Muñoz Language Survey III* (WMLS III; Woodcock, Alcarado, & Ruef, 2017) reported norms, these scores indicate that all participants were either classified as proficient or advanced proficient in English.

It was expected in *Hypothesis-1* that both decoding and language comprehension scores should correlate with one another, but should correlate more largely with reading comprehension as predicted by the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990). Results from the correlation analyses confirmed this prediction and indicated that each of the four reading measures strongly correlated with one another (see Table 34), but language comprehension, decoding, and reading comprehension, had the strongest correlations.

It was also expected (*Hypothesis-2)* that decoding and language comprehension should account for a significant proportion of variance in reading comprehension, but that both the additive combination (RC = D + LC) multiplicative combination (RC = D x LC) should be adequate at accounting for variance. This hypothesis was supported. Similar to *Experiment 1 (Chapter-2)* and *5 (Chapter-4)*, both the multiplicative and the additive model accounted for a significant proportion of variance (67% and 68% respectively), but neither explained additional variance over the other, indicating that both were adequate.

In *Experiment 1 (Chapter-2)*, language comprehension (41%) accounted for significantly more variance in reading comprehension than decoding (21%) for native-English readers and in *Experiment 5 (Chapter-4)* Spanish decoding made no significant contribution to Spanish reading comprehension, while Spanish language comprehension accounted for 32% of variance in reading comprehension these same bilinguals reading in Spanish. It was expected (*Hypothesis-3*) that these proportions would likely also be distinct for the sample of bilingual readers reading in their L2. Specifically, it was expected that English decoding should account for a greater proportion of variance in English reading comprehension compared to the native-English monolinguals (*Hypothesis-3).* Findings indicated that both these hypotheses were also supported. Similar to the native-English readers, language comprehension and decoding both accounted for significant variance and language comprehension accounted for unique variance above and beyond decoding. However, for the bilingual sample reading in their L2, both language comprehension and decoding accounted for higher percentages of variance in reading comprehension than they did for the native-English readers. Together, the additive and multiplicative model also accounted for a higher percentage of variance in the current sample than these models did for native-English readers or the same readers in their L1.

Hypothesis-4 predicted that L2 vocabulary knowledge would contribute unique variance above and beyond decoding and language comprehension as it had done for native-English readers in *Experiment 1 (Chapter-2)*, however this hypothesis was not supported in the current sample.

When cross-linguistic transfer was investigated, a model that included all L2 reading skills as well as L1 decoding and L1 language comprehension as predictors of L2 reading comprehension proved to be the best fit for these data, which partially supported *Hypothesis-5*. It was expected that all L1 reading skills would contribute to L2 reading comprehension either directly or indirectly, however only L1 decoding and L1 language comprehension made significant contributions, though decoding only did so indirectly.

Each of these findings will be discussed in turn below.

5.2.5.1 The Simple View of Reading in a Second Language

Results demonstrated that all four measures of reading skills strongly correlated with one another (see Table 34), but that language comprehension, decoding, and reading comprehension, had the strongest correlations. The strongest correlation was between reading comprehension scores and language comprehension scores at (r = .78). As stipulated in the SVR, decoding and language comprehension should both be more strongly correlated with reading comprehension than with each other. This trend was observed in the data from the current study. These relationships make sense given that the components are independent skills, but both are necessary to contribute to reading comprehension (Gough & Tunmer, 1986; Hoover & Gough, 1990).

Some researchers have found that decoding does not significantly correlate with either language comprehension or vocabulary knowledge for younger readers of English as an L2 (e.g., aged 10 in Proctor, August, Carlo & Snow, 2005). However, given reports that the shared variance between decoding and language comprehension increases with age and skill (Hoover & Tunmer, 1993; Keenan, Betjemann, & Olson, 2008), it makes sense that these constructs would be related in older readers of English as an L2. Importantly, this same trend was also found in *Experiment 1 (Chapter-2)* for English monolinguals, but not for the same sample of bilingual readers reading in Spanish in *Experiment 5 (Chapter-4)*. In contrast, results from Spanish-English bilinguals in *Experiment 5* revealed that Spanish decoding scores were not significantly correlated with Spanish language comprehension or with Spanish reading comprehension. Considering the orthographic structure of each language and the SVR formula (i.e., RC = D x LC), decoding may play less of a role in reading variance for skilled readers of a consistent orthography such as Spanish. In the consistent orthography of Spanish where decoding is mastered early in development (e.g., Defior & Serrano, 2017), the bilinguals' Spanish decoding scores were close to ceiling level and thus have no variance and are no longer related to improvement in reading comprehension or language comprehension which may continue to develop after decoding is mastered. However, in English, due to the inconsistent nature of the orthography, decoding ability continues to develop at later stages of reading (e.g., Seymour, Aro & Erskine, 2003) and thus shared variance between language comprehension and reading comprehension continues. The results from this current study and results from the native English readers in *Experiment 1* (Chapter-2) would support this notion and suggest that decoding may even continue to develop in adult readers. Such results would support claims of the ODH (Katz & Frost, 1992) that reading strategies must be adjusted given the orthography being read and that reading in an inconsistent orthography is supported by both a sub-lexical and a lexical strategy while consistent languages can rely on sub-lexical strategies.

In the current sample of Spanish-English bilinguals, English decoding scores significantly predicted English reading comprehension and explained 53.2% of variance for Spanish-English bilinguals reading in English. As hypothesized, language comprehension was an even better predictor and explained 60.7% of the variance in reading comprehension. A subsequent hierarchical regression demonstrated that after controlling for decoding scores, language comprehension scores explained a further 15% of variance in reading comprehension. Previous studies that have tested the SVR in L2 reading have also reported similar results where language comprehension is a better predictor of L2 reading comprehension than decoding, especially when decoding skills are sufficient (e.g., Paige & Smith, 2017; Proctor et al., 2005). These results support the SVR hypothesis that language comprehension will play a larger role than decoding in explaining reading comprehension for more skilled readers.

As expected, the proportions of variance in English reading comprehension explained by English decoding and English language comprehension were distinct from the contributions of Spanish decoding and language comprehension to Spanish reading comprehension reported from the same Spanish-English bilinguals in *Experiment 5 (Chapter-4).* In *Experiment 5*, Spanish decoding scores did not significantly predict Spanish reading comprehension while Spanish language comprehension did significantly predict Spanish reading comprehension and explained 32% of the variance. As discussed above, these differences make sense given the developmental trajectory of decoding in a consistent versus inconsistent language. Such differences between L1 reading and L2 reading and bilingual readers also lend support to the ODH (Katz & Frost, 1992) because they indicate that Spanish-English bilinguals are adapting different approaches between their consistent L1 and the inconsistent L2. When reading in Spanish, the Spanish-English bilinguals are largely able to read through decoding, and thus decoding has reached ceiling levels of mastery, however in English, the same bilinguals must rely on different strategies that involve language comprehension abilities because decoding is not as easily mastered and readers must rely more on the lexical route to support reading in English.

Compared to the English monolingual readers from *Experiment 1* (Chapter-2) the relative contribution of decoding and language comprehension to reading comprehension from Spanish-English bilinguals reading in English is also somewhat distinct. While language comprehension ($R^2 = 0.41$) also predicted more variance in English reading comprehension than decoding ($R^2 = 0.21$) for English monolinguals, each component explained less variance in reading comprehension than they did for the Spanish-English bilinguals reading in English. However, the lower scores on each of the WMLS III subtests indicate that the Spanish-English bilinguals were less skilled in English than the English monolinguals and therefore may still be developing these skills, resulting in a higher proportion of variance among the scores than the English monolingual readers. Previous research has also reported similar findings that the SVR predicts unique variance for L2 readers of English compared to English monolinguals (Goodwin, August & Claderon, 2015; Nakamoto, Lindsay & Manis, 2008; Proctor et al., 2005; 2006).

Since the initial publication of the SVR, several studies have found the product model of the SVR to be more effective than the additive model in predicting reading comprehension (Carver & David, 2001; de Jong & van der Leij, 2002; Joshi & Aaron, 2000). In contrast, similar to the results in the current study, some evidence suggests that the additive model of the SVR may explain more variance in reading comprehension than the product model (Dreyer & Katz, 1992; Chen & Vellutino, 1997; Neuhaus et al., 2006). However, not all studies that test the SVR model have compared the additive and multiplicative model as we have done in the current study. For example, some studies use only hierarchical regressions or path analysis to evaluate the relationship of decoding and language comprehension to reading comprehension (e.g., Goodwin, August & Calderon, 2015; Paige & Smith, 2017; Proctor et al., 2005;). While these types of analyses are informative, they fail to fully evaluate the hypothesized nature of the component variables from the SVR. The current study contributes to existing literature by reporting an account of both the additive and multiplicative model of the SVR in Spanish-English bilinguals and considered the role of both the L1 and the L2. Further, these findings were contextualised in comparison to their monolingual English peers.

The additive combination of language comprehension and decoding explained 68% of the variation in reading comprehension, while the multiplicative model accounted for a marginally smaller 67% of the variation in reading comprehension in this sample. Another key assumption of the SVR is that in a multiplicative mode (RC = D x LC), if either of these variables is null, or 0 ability, then no matter how much skill they have with the other variable, they will not successfully comprehend. In other words, both decoding and language comprehension skills are necessary, but not solely sufficient conditions for the development of reading comprehension (Gough & Tunmer, 1986). Since both the linear and multiplicative combination of the decoding and language comprehension variables explained an equitable amount of variance in reading comprehension, our data fail to support this assertion of the SVR. *Experiment 1* (Chapter-2) and *Experiment 5* (Chapter-4) also showed similar trends where the linear and multiplicative combinations of the component variables explained similar amounts of variance. Importantly, this may indicate that there could be some ability in reading comprehension even if there is no skill in either decoding or language comprehension (e.g., if LC = 0 and D = 0.5, then RC = 0.5). In their initial sample, Hoover and Gough (1990) found that the product term of the SVR predicted reading comprehension above and beyond that of the linear relationships with reading comprehension. However, the sample they used was that of bilingual Spanish-English children. Although the difference between the additive combination (R^2 = 68%) and the multiplicative combination (R^2 = 67%) is only marginal, we failed to find the same effect in the current sample of Spanish-English bilingual readers.

The results from the current sample and previous research on monolingual English speakers may suggest that the contribution of the components additively to reading comprehension may better characterize reading in an inconsistent orthography than an interaction of these components. If an additive model of the SVR is sufficient, then these findings may also imply that both decoding and language comprehension skills may not be strictly necessary in an inconsistent language to yield some level of skill in reading comprehension. However, since variance in Spanish reading comprehension could also be accounted for by both the multiplicative and additive formula of the SVR in the same Spanish-English bilinguals reading in Spanish, perhaps this premise of the SVR is not applicable at all, at least to adult skilled readers.

Reading Behaviour Between a Consistent and an Inconsistent Orthography

5.2.5.2 The Role of Vocabulary in the Simple View of Reading in a Second Language

Experiment 1 (Chapter-2) found that vocabulary knowledge made a significant contribution to the variance in reading comprehension by 6.1% above and beyond that of decoding and language comprehension in skilled native English monolingual readers. In the current experiment, English vocabulary knowledge did significantly predict English reading comprehension independently and explained 36% of the variance for Spanish-English bilingual adult readers. However, in contrast with findings from the monolingual English sample, when English vocabulary scores were added to the SVR model, they did not yield a significant improvement on the model above and beyond decoding and language comprehension. Since vocabulary knowledge has been found to be delayed in L2 learners in both the L1 and the L2 (Bialystok, 1988; Rosenblum & Pinker, 1983) and since the bilinguals in the current sample scored significantly lower on the Picture Vocabulary subtest than English monolinguals, these results may imply that Spanish-English bilinguals are able to build their L2 reading acquisition without relying on vocabulary to the same extent as English monolinguals.

Vocabulary may aid in the use of large grain reading strategies and the use of the lexical route required for reading in an inconsistent orthography. As the more exposure to vocabulary, the more this knowledge may be stored in the lexicon. Thus, in terms of the Psycholinguistic Grain Size Theory (Zeigler & Goswami, 2005), these results may indicate that the Spanish-English bilinguals continue to use a small-grain size strategy when reading in English if they are not relying on vocabulary. This strategy is not efficient for reading English, and may hinder Spanish-English bilinguals. Further support for this claim stems from the results from *Experiment 5* (Chapter-4), which revealed that Spanish vocabulary knowledge was not a significant independent predictor of reading comprehension in Spanish and made no significant contributions to variance in reading comprehension above and beyond the SVR model for Spanish-English bilinguals reading in Spanish. Thus, this may imply some extent of transfer of Spanish reading strategies to approach English. The next section will now discuss the extent of the role of cross-linguistic transfer in L2 reading.

5.2.5.3 Cross-Linguistic Transfer and the Simple View of Reading

Cross-linguistic transfer of L1 reading skills to support reading in the L2 has been reported across the literature (e.g., Bialystok, Majumder, & Martin, 2003; Cisero & Royer, 1995; Dickinson, McCabe, Clark-Chiarelli & Wolf, 2004; Lindsey, Manis, & Bailey, 2003; Manis, Lindsey, & Bailey, 2004; Verhoeven, 1994). While it appears as though L1 phonological awareness and word identification skills are good predictors of L2 reading, far less is known about the role of language comprehension and vocabulary knowledge. Multivariate path analyses were used in the current study to investigate the role of cross-linguistic transfer and to explore mediators between the component variables and reading comprehension and to estimate model fit.

In the model (Figure 46), several variables made direct contributions to English reading comprehension including English language comprehension, English decoding, and Spanish language comprehension. Evidence of transfer was found through the direct relationship between Spanish language comprehension and English reading comprehension. This would suggest that Spanish language comprehension skills transfer directly to support English reading comprehension in the current sample of Spanish-English bilinguals. These findings align with previous research that has also found evidence of cross-linguistic transfer from a first language to a second language (e.g., (Lindsey, Manis, & Bailey, 2003; Relyea & Amendum, 2020; Riccio et al., 2001). However, Proctor et al. (2006) report specifically that there was no evidence that L1 language comprehension transferred to L2 reading comprehension. Further, the Interdependence Continuum hypothesised by Proctor, August, Snow, and Barr (2010) reported evidence of strong interdependence for alphabetic knowledge for Spanish-English bilinguals, a moderate interdependence for reading comprehension and a mild interdependence for Spanish oral language related to English reading comprehension. The results from the current study do not support this account. This difference may be a result of the age of the current sample and that of Proctor and colleagues. The current sample consisted of adult Spanish-English bilinguals while Proctor and colleagues' sample were younger fourth-Grade Spanish-English bilinguals (aged 10). There is sufficient evidence from tests of the SVR that language comprehension skills play a larger role than decoding skills for older readers (e.g., Hoover & Gough, 1990), thus it is reasonable to assume that L1 language comprehension may yield the same relationship with L2 reading comprehension. Further, in the current sample, the relationship between Spanish language comprehension and English reading comprehension was also partially mediated by its contribution through the combined path of both English decoding and English language comprehension. However, this indirect relationship was not significant through these same variables separately. Therefore, it appears that the indirect influence Spanish Language comprehension has on English reading comprehension is mediated through an interaction between English decoding and English language comprehension but may not support these variables individually. Further research from different age groups is needed to fully explore the cross-linguistic relationships between language comprehension and reading comprehension.

Spanish decoding did not make any significant direct contributions to English reading comprehension but did make significant indirect contributions via English language comprehension and made significant total contributions despite a nonsignificant indirect contribution through English decoding. This indirect relationship may suggest that the relationship between Spanish decoding and English reading comprehension is fully mediated by English language comprehension skills. These results are surprising given that previous research has generally shown that phonological decoding skills in the L1 are usually predictive of the same skills in the L2 (Bialystok, Majumder, & Martin, 2003; Cisero & Royer, 1995), but do not tend to report a relationship with language comprehension skills. However, Proctor et al. (2006), who tested the SVR directly, did report that L1 real word decoding skills were associated with better language comprehension and reading comprehension skills in the L2 (Proctor, August, Carlo & Snow, 2006). The decoding skill in the current study was also that of real word decoding, suggesting that this skill in particular may yield similar beneficial impacts on L2 language and reading comprehension. Further, given the low English decoding scores in the current sample, it is possible that these readers may be drawing from the richer experience with decoding in their L1, which was close to perfect ability in the current sample, to support language comprehension.

While Proctor et al. (2006) found that L1 vocabulary explained unique variance in L2 reading comprehension after controlling for L2 language comprehension and decoding, the current study did not. However, these results may not be surprising given that L2 vocabulary did not explain any unique variance in L2 reading comprehension in the current study. Further, when these sample participants were tested in their L1 (Spanish) *Experiment 3 (Chapter-3)*, L1 vocabulary did not explain any unique variance in L1 reading either. Other studies have also reported findings that show no contribution of Spanish vocabulary to English reading comprehension (Mancilla-Martinez & Lesaux, 2010; Nakamoto, Lindsey, & Manis, 2008). It is possible that these differences may be related to age and experience of participants or the type of English instruction they received in each of the different samples. Carlo et al. (2014) reported that the relationship between L1 and L2 reading abilities was mediated by type of English instruction. Specifically, students who were taught only in English showed no relationship between their L1 and L2 reading abilities, but there was a relationship for the students who were instructed bilingually. The typical instruction system in Granada involves English-only instruction until age 12 and then bilingual instruction after. Further, the students in the current sample were from Spain and living in Spain, while the sample from Proctor et al. (2006) were living in the United States. Additional work with bilinguals across different countries who had different learning experiences is needed to fully understand this relationship.

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Since the model that included L1 reading measures accounted for more variance in L2 reading comprehension than either the additive or the multiplicative model with only L2 reading abilities, (72% vs. 68% and 67% respectively), the role of transfer must be considered within the SVR model for L2 reading. This finding would also support Cummins's (1979, 1984) theories of a common underlying proficiency, that L1 reading skills are vital to understanding variation in L2 reading comprehension.

5.2.5.4 Limitations and Further Research

Although these findings are informative, they are still limited in scope. Bilingual research must contend with a variety of factors that may influence reading. For example, variables such as the amount of time spent learning an L2, English instruction practices in school, amount of time spent speaking an L2 at home, etc. are all some of the factors that affect second language acquisition and second language reading (e.g., Bedore et al., 2012; Dunn & Fox Tree, 2009; Schmid & Yılmaz 2018; Unsworth, Chondrogianni, & Skarabela 2018) these variables were not all assessed in the current study.

Additionally, the current study did not measure other reading abilities such as morphological knowledge, working memory etc. which may also impact L2 reading (e.g., Gorman, 2012; Swanson, Orosco, & Lussier, 2015; Miyake & Friedman, 1998). Future studies would benefit from incorporating all of these variables to better characterise bilingual reading.

5.2.5.5 Conclusion

Findings from this study have implications for both research and practice. First, for research, the findings indicate that the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990) can accommodate the complexity of second language reading in comparison to first language reading, but that the role of transfer must be considered for a better characterization of L2 reading. It is important that future research expands on Gough and Tunmer's (1986) initial hypothesis to accommodate bilingual readers or second language learners of English. An integration of Cummins' (1979) interdependence hypothesis and Proctor et al. (2010)

Interdependence Continuum should be considered in parallel when investigating bilingual reading. The findings from the current study highlight the continued importance of L1 skills in L2 reading for Spanish-English adult readers, particularly L1 language comprehension, and raise the question of the potential influence of age and learning programs. These questions merit further investigations in the future.

For practice, this study emphasises the importance of measuring L1 reading abilities, especially word-reading skills, and language comprehension skills to aid in supporting the same skills in a second language. The ability to predict reading outcomes based on related reading abilities in the first language can serve as an early identifier in detecting future risk or reading difficulties or language difficulties. To this end, it is essential to demonstrate a full profile of cognitive correlates in reading in a first and second language in readers from all age groups. Further, in contrast to findings from English monolingual readers, L2 vocabulary was not a strong predictor of L2 reading comprehension, which may have hindered reading comprehension for the current sample of Spanish-English bilinguals. These findings may suggest than an emphasis on L2 vocabulary would be beneficial in bilingual reading instruction.

Taken together, these findings extend the current literature by providing an account of the L1 and L2 predictors of L2 reading comprehension in Spanish-English bilingual readers and contextualised these findings in comparison to their monolingual English peers. These findings highlight the role of cross-linguistic transfer and the role of orthography in driving developed L2 reading skills. The next section of the current thesis will further contextualise these findings by investigating reading strategies of the same sample of Spanish-English bilinguals using eye-tracking.

5.3 Experiment 8: Eye Movement Patterns in a Second Language (Spanish-English Bilinguals Reading in English)

5.3.1 Introduction

The findings from *Experiment 7* suggest that compared to the readers of English in *Experiment 1* (Chapter-2), Spanish-English bilingual readers may rely on distinct profiles of reading abilities to support reading in an inconsistent orthography, with evidence of transference of reading abilities from the L1 to support the L2.

As previously discussed, reading strategies may differ between readers of consistent versus inconsistent orthographies. Readers of inconsistent orthographies such as English, may learn to recognize words via the lexical route using larger-unit grain sizes, such as onsets, rimes, and whole words to read while readers of consistent orthographies can reliably process small-grain via the sub-lexical route (e.g., Katz & Frost, 1992; Rau, et. al., 2015; Ziegler, et. al., 2001). Such differences between reading strategies between a consistent and inconsistent orthography raise the important theoretical question of how bilinguals who read both a consistent and inconsistent language are able to manage their reading strategies between languages. The current study (*Experiment 8*) used eye-tracking methodology to examine how bilinguals adapt their reading strategies between an L1 and an L2 and the extent to which their L2 reading resembles that of a native reader of the same language.

Objective measures of reading strategies such as eye movements may be a more sensitive measure that can be used to further the findings from *Experiment 7*. Since the depth of a language's orthography may influence reading strategies, orthographic depth may also influence eye-movement patterns, and therefore eye movement patterns while reading may also vary across languages. Thus, comparing eye movement patterns of bilinguals reading in both their L1 and L2 can detect transfer of language abilities, and at which point in the time course of reading they may occur. Similarly, comparing eye movements of bilinguals reading in their L2 with monolingual readers reading the same language, may demonstrate the extent to which a bilingual reader applies similar or distinct strategies to a native. Eye movements may provide additional information about reading strategies above and beyond that of offline reading assessments. Examining eye movements thus may reveal a greater understanding of the cognitive processes of reading and comparing such processes to offline measures of reading may further develop the complete picture of reading.

As discussed previously, there are several reasons why reading in an L1 may be distinct from reading in an L2 for bilingual readers, and why reading in an L2 may be different from native readers reading the same language. Imaging studies have been useful in uncovering some of these similarities and differences in each of these reading processes (e.g., Brignoni-Perez, Jamal & Eden, 2020; Jamal et al., 2012; Kovelman, Baker & Petitto, 2008; Paulesu et al., 2000), and a number of eye-movement studies have served as a useful tool in the same investigation. These investigations will be discussed below.

5.3.1.1 Eye Movements in Bilingual Readers between an L1 and an L2

Eye-tracking is a particularly robust and objective measure of reading that allows for investigation of nuanced reading strategies. Using eye-tracking in cross-linguistic research is useful in examining the processes that differ between reading in an L1 versus and L2 for bilinguals and processes that may transfer from a first language to a second. Cross-linguistic research using eye movements has demonstrated that bilinguals may be able to adjust their strategies based on the orthography being read, however these strategies may or may not adjust to the point of matching those of native readers. This section will review several eye movement studies that have demonstrated strategies bilinguals used between an L1 and an L2 of differing orthographic consistency, and studies that have compared L2 reading strategies with native monolingual readers.

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Eye-tracking has been successfully used to investigate potential influences of bilingual processing (for a recent review, see Titone, Whitford, Lijewska, & Itzhak, 2016). Eye movement research with bilinguals generally suggests that bilingual readers make shorter fixations, longer saccades, and fewer regressions in their dominant language, which tends to be their L1 (Altarriba, Kambe, Pollatsek, & Rayner, 2001; Altarriba, Kroll, Sholl, & Rayner, 1996; Balling, 2013; Bultena, Dijkstra, & van Hell, 2014; Friesen & Jared, 2007; Hoverstern & Traxler, 2015; Titone, Libben, Mercier, Whitford, & Pivneva, 2012).

Duyck, Van Assche, Drieghe and Hartsuiker (2007) were among the first to investigate the cognate facilitation effect using eye-tracking methodology. They measured first fixation duration, gaze durations, and total reading time in Dutch-English bilinguals while they read sentences in English (their L2) with an embedded target that was either a Dutch-English cognate or an English control. A cognate facilitation effect was found for both late and early eye movement measures (as indexed by shorter first fixation durations, gaze durations and total reading times) such that these eye movement measures were all faster when reading cognates than when reading controls. In a later study by the same group, Van Assche et al. (2009) repeated this method, but this time Dutch-English bilinguals read sentences in Dutch (their L1) embedded with target words that were either cognates or Dutch controls. Similar to findings from the previous study, a cognate facilitation was found for early eye movement measures (the authors did not report late eye movement measures). Taken together, these studies suggest that bilinguals may process reading non-selectively even in their dominant language at least for alphabetic languages.

Other studies using eye movement techniques have reported evidence of transfer (e.g., Libben & Titone, 2009; Titone, Libben, Mercier, Whitford, & Pivneva, 2011). For example, Libben and Titone (2009) measured eye movements (first fixation duration, gaze duration, go-past times, and total reading times) of French-English bilinguals (French-dominate but proficient in English) as they read English (their L2) sentences either containing cognates or interlingual homographs (e.g., *coin, meaning corner in French*). As previously discussed, while a facilitation effect is generally found for cognates (e.g., De Groot & Nas, 1991; Dijkstra, De Bruijn, Schriefers, & Brinke, 2000), interlingual homographs have been found to hinder processing (e.g., Dijkstra, Grainger & Van Heuven, 1999; Dijkstra, Timmermans, & Schriefers, 2000; Dijkstra, Van Jaarsveld, & Ten Brinke, 1998; Macizo, Bajo & Cruz Martín, 2010). The sentences were further manipulated to be either a low semantic constraint sentence (no context given to the target word) or a high semantic constraint sentence (a lot of contexts given to the target word).

Results demonstrated that in the low-constraint sentences, a cognate facilitation effect was found from early measures of lexical access as indexed by shorter first fixation durations, shorter gaze duration, and more skips when reading cognates compared to control words, as well as with late measures as indexed by shorter go-past time total reading time when reading cognates compared to control words. Similarly, there was also an interlingual homograph interference in low-constraint sentences indexed by both early (i.e., longer first fixation durations and gaze durations when reading interlingual homographs compared to controls) and late (i.e., longer go-past times and total reading times when reading interlingual homographs compared to controls) measures of lexical access. Such results indicate that when context is ambiguous, both languages may be activated at one time. In high-constraint sentences however, only the early-stage comprehension measures showed evidence of nonselective language. There was no evidence of cognate facilitation or interlingual homograph interference in the late-stage measures of comprehension for the high-constraint sentences. Thus, when context is readily available, both languages may be activated in early stages of reading comprehension, but context ambiguity is quickly resolved at later stages of comprehension.

Taken together it seems that there is strong evidence that language access is non-selective and both languages are available simultaneously to a bilingual reader. So just how well can bilinguals adjust their strategies between languages varying in orthographic consistency to meet the unique demands of the languages being read?

Some findings have suggested that bilinguals are in fact able to adjust their reading strategies between languages even when reading identical words. For example, Egan et al. (2019) investigated whether bilinguals would read identical words and nonwords differently depending on whether they were embedded in Welsh versus English sentences, using eye movements. A significant language x lexicality effect was reported for most eye movement measures included in the study (i.e., First fixation duration, gaze duration, regression path (also called go-past time), and total reading time). Specifically, when reading cognates embedded in Welsch sentences, the more consistent orthography, bilinguals employed more total and first pass fixations (associated with early lexical access) compared to when they read the cognates in English. The bilingual readers also showed a pattern of longer processing times for Welsh vs. English cognates in measures that are typically associated with later lexical access (i.e., go-past time and total reading time). Further, post hoc analyses of initial eye landing positions of the cognates revealed that participants' eyes initially landed further to the left on the cognate target word within Welsch sentences compared to English sentences. Taken together, these findings were interpreted to suggest that the bilinguals adapt a smaller grain size strategy depicted by more frequent fixations across a greater area of the target word when reading words within the context of the Welsh language compared to a larger grain strategy adapted when reading in the context of English sentences.

The findings reported by Egan et al. (2019) also accord with those reported by Ziegler et al. (2001) who found that native-German (a consistent orthography) and native-English (an inconsistent orthography) readers read identical words differently. To review, results length effects and body-N effects from this study suggested that German readers relied more on a small-unit decoding strategy while the English readers employed a larger-unit lexical strategy even when reading identical words. GPCs are translated more efficiently in the consistent German language while readers of English need to use the lexical routes to support reading. Although Germans were slightly slower at reading overall, this effect was not significant, further, both groups had a high level of reading accuracy indicating that each of these strategies supports efficient reading.

It should be noted, that although most eye movements reported in the study by Egan et al. (2019) demonstrated a language x lexicality interaction, there was only a significant main effect of language for the early eye movements (first fixation duration, and gaze duration). Further, most of the trends exhibited for cognates showed the opposite patterns in response to reading pseudowords such that when the pseudowords were embedded in English sentences, the bilinguals exhibited shorter but more frequent fixations, and longer go-past times compared to when they were embedded in Welsh sentences. Averages for total reading times were not reported. Thus, these results should be interpreted with caution, and further research is needed to verify such findings.

In a second experiment, Egan et al. (2019) then compared Welsh-English bilinguals’ eye movements while reading the English sentences with monolingual English readers to determine whether knowledge of Welsh may transfer to affect eye movements of the Welsh readers reading in English. Results revealed that the bilinguals’ eye movements were very similar to monolinguals’ when reading English and no significant differences were found between the eye movement measures including initial landing position. These results would suggest that fluent bilingual readers can adjust their strategies to meet the demands of an L2 with little or no evidence of influence from the L1.

In summary, it appears as though fluent bilinguals may be able to adjust their reading strategies to the point where they begin to appear native-like in their L2 even when orthographic consistency differs between the two languages. However, for less proficient bilinguals, there still may be evidence of transfer from an L1 to an L2 which may occur at certain points in the reading process. Reported findings from these studies may support the Psycholinguistic Grain Size Theory (Zigler & Goswami, 2005), suggesting that reading in a consistent language is reliably achieved through the sub-lexical route which is reflected by smaller-grain processing, while reading in an inconsistent language must use a lexical strategy which involves larger-grain processing. Such findings would also support the ODH (Katz & Frost, 1992). However, there are some areas of this research that require further clarity, in particular, the role of eye movement measures that represent late lexical access (i.e., go-past times and total reading times). Further, although examining cognates and interlingual homographs are informative, these types of words are acquired in both languages and thus may be represented differently from words that are only acquired in one language. Examining length and frequency effects on words that are distinct in each language on the other hand, may be more useful at revealing distinct reading strategies between reading a consistent versus inconsistent orthography. Indeed, this topic remains understudied across the bilingual reading literature (e.g., Titone, Whitford, Lijewska, & Itzhak, 2016). For these reasons, the current study examined length and frequency effects in both early and late eye movement measures of bilingual readers. This methodology was useful in the previous *Experiments 2* (Chapter-2)*, 4* (Chapter-3)*, and 6* (Chapter-4)*.* The next section will discuss previous findings of bilingual reading strategies from examining length and frequency effects in eye movements.

5.3.1.2 Length and Frequency Effects between an L1 and an L2 in Bilingual Reading

Most research on length and frequency effects in reading have come from studies using monolinguals. As previously discussed, reading strategies between readers of consistent versus inconsistent orthographies have been investigated by examining length and frequency effects between native readers of different orthographies. To review, research has reported larger frequency effects (Landerl, Wimmer & Frith, 1997; Rau, Moll, Snowling & Landerl, 2015) and lexicality effects (Paulesu et al., 2000), but smaller length effects (Ellis & Hooper, 2001; Goswami, Gombert, & Fraca de Barrera, 1998, Rau, Moll, Snowling & Landerl, 2015) for readers of inconsistent orthographies compared to readers of consistent orthographies.

Findings from *Experiment 6* (Chapter-4) of the current thesis demonstrated significant differences between reading strategies of native-Spanish and native-English readers. Specifically, eye movements measured at the sentence-level from native readers of Spanish indicated a pattern of shorter, but more frequent fixations and regressions, which may be indicative of a decoding strategy of reading (Rayner, 1998, Rayner, 2009; Liversedge, Paterson, & Pickering, 1998, Korneev, Matveevn, & Akhutina, 2020) compared to readers of English. Both early and late eye movements were sensitive to frequency effects and length effects, apart from first fixation durations. Compared to native-English readers, frequency effects were smaller, and length effects were longer for native-Spanish readers, which was apparent in all eye movement measures. Taken together these findings suggest that a sub-lexical decoding strategy may not necessarily be the only reading strategy for adult readers of a consistent orthography, but there is greater reliance on this strategy compared to readers of an inconsistent orthography. However, all of these findings come from participants reading in native language. The next theoretical question that is raised from these results is how will bilinguals reading strategies in their L2 compare to their L1, and to what extent will they be similar or different to reading strategies of native readers of their L2? The current study aimed to investigate this question.

Some studies have examined length and frequency effects in bilinguals between their L1 and L2 in French-English bilinguals, two inconsistent orthographies, with English being more inconsistent than French. For example, investigations of length and frequency effects in eye movements of French-English bilinguals suggest that bilinguals' L2 experience may modulate effects of frequency. For instance, Whitford and TItone (2012; 2015; 2017) found that English-French bilinguals and French-English bilingual adults' experience reduced L2 versus L1 lexical accessibility (indexed by larger word-frequency effects in the L2 vs. L1) during paragraph reading. Participants were asked to read paragraphs embedded with words that were manipulated for length and frequency in both their L1 and their L2. Language experience was assessed via self-reported current percentages of time exposed to L1 versus L2. Larger frequency effects were found for the L2 compared to L1 reading, for first fixation duration, gaze duration, and total reading times. The magnitude of the frequency effect was also larger for bilinguals with lower L2 exposure. Length effects were not reported. Later work by the same research group also demonstrated that less L2 experience yielded slower reading rates, longer fixations, shorter forward saccades, and more regressions during sentence reading (Whitford & Titone, 2015) and larger L2 frequency effects in gaze duration, go-past time, and total reading times (Whitford & Titone, 2017).

Interestingly, however, eye movement studies comparing reading in monolingual and bilingual readers demonstrate comparable reading strategies. For example, Cop, Keuleers, Drieghe and Duyck (2015) found comparable frequency effects between adult Dutch-English bilinguals reading in English compared to English monolinguals during novel reading. Similarly, Gollan et al., 2011, for comparable word-frequency effects in English monolinguals, Dutch–English bilinguals, and Spanish–English bilinguals, during sentence reading.

Results from the current sample's reading skills measured in *Experiment 7*, indicated that participants were either proficient or advanced proficient in their skills according to the norms reported by the WMLS III. However, these reading ability scores were still significantly poorer than those of native-English participants, and results from the path analysis demonstrated evidence of transfer from the L1 to the L2. Thus, it is reasonable to classify the current group of bilinguals as proficient in English, and to expect that some reading strategies may show evidence of transfer, but given the evidence above, reading strategies may look largely native-like. For these reasons, comparisons will not only be made between bilinguals reading in the L1 and L2, but also between native-English monolinguals and the

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Spanish-English bilinguals reading in English.

5.3.1.3 The Simple View of Reading Variables and Eye Movements During L2 Reading

Eye-tracking is a useful tool in investigating bilingual reading processes and cross-linguistic phenomena. As previously discussed, several studies have also reported that eye movements are influenced by individual differences in reading abilities in English (Ashby and Clifton 2005; Ashby et al., 2012; Chace et al., 2005; Jared et al., 1999; Luke et al., 2015; Veldre & Andrews, 2014; 2015), and there is a large body of evidence that has investigated cognitive predictors of L2 reading outcomes (see August & Shanahan, 2006, for a review). What is less apparent however, is whether eye movement measures can also effectively reflect specific reading skills (i.e., the component skills from the SVR) developed by bilinguals that are predictive of L2 reading outcomes. Although some research has compared measures of reading comprehension with eye movement measures in English, (e.g., Ashby and Clifton 2005; Ashby et al., 2012; Chace et al., 2005; Jared, Levy & Rayner, 1999; Luke et al., 2015; Veldre & Andrews, 2014, 2015a, 2015b), and in other languages such as Finnish (Häikiö, et. al., 2009). Very few studies have done the same for L2 readers (though see e.g., Blinnikova, Rabeson & Izmalkova, 2019; Whitford & Joanisse, 2018; Whitford & Titone, 2015; 2016).

A comparison of online eye tracking measures with offline reading skills is an informative way of examining specific reading strategies employed by bilinguals as they read in their L2. For these reasons, the current study will compare eye-movement patterns of Spanish-English bilinguals reading in their L2 (English) with native English monolingual readers and with their L1 reading (Spanish). These comparisons will demonstrate the extent to which bilingual eye movements, and thus their reading strategies, change from their L1 to their L2 and how those strategies compare to those of native readers. Together, the findings from the proposed study will also show the extent to which experienced Spanish-English bilinguals have adapted their reading strategies when processing a text in an L2 with a deeper orthography thus providing support for the ODH (Katz & First 1992) and the PGST (Ziegler & Goswami, 2005) or whether bilinguals continue to show language transference despite efficient comprehension. Further, determining whether current models predominantly applied to reading in the English language, such as the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990), is a language specific model or whether it can be applied as a universal model of reading. The benefit of testing the SVR with other languages and non-native speakers is to provide evidence-based teaching strategies and diagnostics methods for reading disabilities for non-native readers of English, and for languages other than English.

5.3.2 Experiment 8: The Current Experiment

The first goal of the current experiment was to produce an on-line record of reading strategies measured by eye movements employed by Spanish-English bilinguals as they read sentences to extract meaning in their second language (English). An examination of these eye movements may be a more sensitive measure of the strategies employed by readers reading in their L2 than offline measurements (e.g., WMLS III).

A second aim of the current experiment was to compare these online measures with the component measures from the SVR that were measured offline. These analyses will provide a further understanding of developed component skills and their relationship to cognitive processes involved in reading as measured by eye movement strategies.

Finally, similar to the experiments by Egan et al. (2019), the eye movements observed in the current experiment will be compared to the eye movements employed by English monolingual readers who read the same sentences, and also the eye movements from the same sample of Spanish-English bilinguals observed in Spanish reading in order to investigate evidence of cross-linguistic transfer.

5.3.2.1 Hypotheses

The current experiment aimed to investigate the following hypotheses:

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1. Since reading in English demands a reading strategy that uses larger grains of information, and a lexical procedure rather than relying on a sub-lexical decoding procedure (Katz & Frost, 1992; Ziegler & Goswami, 2005), It was expected that Spanish-English bilinguals reading in English would demonstrate similar length and frequency effects observed in the native-English readers from *Experiment 1* (Chapter-2). Specifically, Frequency effects were expected to appear in each eye movement measure, but length effects were expected for the late eye movement measures.

2. It was also predicted based on findings from behavioural results from *Experiment 7* and findings from eye movement research (e.g., Egan et al., 2019; Whitford & Titone, 2015; 2017) that bilinguals use distinct strategies to process reading in their L1 and L2 and will therefore show distinct eye movements reflecting those strategies. Specifically, it was expected that Spanish-English bilingual readers would exhibit relatively shorter fixation durations but more fixations, forward and backward saccades while reading in Spanish compared to reading in English. These findings have been reported in previous bilingual studies (Altarriba, Kambe, Pollatsek, & Rayner, 2001; Altarriba, Kroll, Sholl, & Rayner, 1996; Balling, 2013; Bultena, Dijkstra, & van Hell, 2014; Friesen & Jared, 2007; Hoverstern & Traxler, 2015; Titone, Libben, Mercier, Whitford, & Pivneva, 2012).

3. Given that frequency plays a more important role in meeting the demands of the inconsistent English orthography, whereas length plays a more important role for the consistent Spanish orthography. It was also predicted that bilingual readers will show relatively smaller length effects, but larger frequency effects when reading in their L2 compared to reading in their L1. We expect this result because bilingual participants can rely more on decoding in the consistent orthography of Spanish to process a

text, while needing to rely on later measures of reading as a strategy to process linguistic information when reading in English.

4. Given that *Experiment 7* in the current Chapter demonstrated some evidence of cross-linguistic transfer, and the finding that the Spanish-English bilinguals scored significantly poorer on the measures of reading, it was expected that comparisons between the current sample of bilinguals and the native-English readers, would demonstrate some degree of transfer. Specifically, since Spanish language comprehension made a direct contribution to English reading comprehension, it was expected that first fixation durations, which significantly correlated with this skill in Spanish reading (*Experiment 6* in Chapter-4) would likely differ for bilingual readers. However, given that some research has indicated that bilingual adult readers demonstrate no significant differences in reading strategies compared to native readers (e.g., Egan et al., 2019; Cop, Keuleers, Drieghe & Duyck, 2015; Gollan et al., 2011), it was expected that most other eye movement measures and length and frequency effects would not be significantly different from native readers.

5. Eye movement measures such as fixation count and fixation duration are considered to reflect decoding strategies (e.g., Rayner, Slattery, Drieghe, & Liversedge, 2011) and thus it was expected that these eye movements measured at the sentence-level would significantly correlate with the decoding scores measured in *Experiment 7*. Total reading time and regressions on the other hand should correlate with higher order language measures such as vocabulary, language comprehension and reading comprehension (e.g., Liversedge, Paterson, & Pickering, 1998; Rayner, 1998).

6. Since the behavioural data from *Experiment 7* in the current Chapter demonstrated that language comprehension skills were better predictors of reading comprehension than decoding, it was predicted that late eye movement measures of reading measured at the word-level (i.e., go-past time and total reading time, thought to

reflect higher order language skills) would be better predictors of reading comprehension abilities than early eye movement measures of reading in this sample.

5.3.3 Methods

5.3.3.1 Participants

The same 38 participants from *Experiment 5,6* (Chapter-4) and *7* in the current chapter participated directly afterwards in this experiment.

5.3.3.2 Measures and Materials

The methods and materials were identical to those used in *Experiment 2* (Chapter-2).

5.3.3.3 Apparatus

The apparatus was identical to that used in the pilot experiment and *Experiment 2* (Chapter-2).

5.3.3.4 Procedure

The procedure was nearly identical to that of *Experiment 2* (eye-tracking experiment with English participants) (Chapter-2). The only difference was that the current experiment was completed in a laboratory on the University of Granada's campus.

5.3.4 Results

After eye-tracking data had been collected the same cleaning procedure as was used in the pilot experiment was used in the current experiment to remove very short (< 80 ms) or very long fixations (> 1,000 ms) (Inhoff & Radach, 1998; Liversedge, Paterson, & Pickering, 1998).

As in *Experiment 2*, global eye movement measures (fixation and regression count, fixation duration, and total reading time) were calculated across the whole sentence. The local measures were calculated from long and short high-frequency and low-frequency words

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These measures included first fixation duration, gaze duration, go-past times and total fixation time (see Table 8 (Chapter-2) for the definitions of each of these measures).

The current experiment investigated eye movement patterns in Spanish-English bilinguals reading sentences for meaning in English. Before eye movement measures were analysed, the TRUE-FALSE critical comprehension scores for the sentences for each participant were calculated. All participants scored 80% or higher and thus no participant was excluded from analysis.

5.3.4.1 Sentence-Level Measures for Spanish-English Bilinguals in English

Means and standard deviations for each eye movement measure are tabulated in Table 38. These scores were calculated based on average scores across the entirety of each sentence.

Table 38. Mean Eye-Movement Measures Across Sentences for Spanish-English Bilinguals Reading in English

Measure	Fixation Count	Average Fixation Duration (ms)	Regression Count	Total Reading Time (ms)
Mean (SD)	15.02 (3.88)	200.34 (17.99)	5.18 (1.89)	3643.49 (978.17)
Range	14.17 - 20.02	171.70 - 233.27	5.69 - 8.08	3295.52 - 5139.61

5.3.4.2 Word-Level Measures Descriptive Statistics and Length and Frequency Effects

To investigate word-level effects on eye movement strategies, a 2 (frequency: low vs high) x 2 (length: long vs short) repeated measures ANOVA was conducted for each of the four eye movement measures (First fixation duration, gaze duration, go-past time, and total reading time) with Bonferroni corrected alphas of 0.013 to investigate the effects of length and frequency. Mean measures are tabulated in Table 39.

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Table 39. Mean Eye-Movement Measures for Frequency x Length for Spanish-English Bilinguals Reading in English

Measure Mean (SD)	First Fixation Duration	Gaze Duration	Go-Past Times	Total Reading Times
HF_Short Words	193.14 (22.07)	254.10 (44.59)	248.70 (66.87)	433.83 (114.17)
LF_Short Words	211.26 (37.47)	302.26 (84.98)	265.92 (127.33)	479.02 (208.40)
HF_Long Words	194.46 (20.00)	272.42 (64.83)	260.14 (76.54)	431.29 (114.87)
LF_Long Words	212.79 (25.51)	319.06 (64.23)	332.38 (89.39)	550.26 (152.21)

There was a significant main effect of frequency for all eye movement measures. Specifically, as seen in Table 39, shorter first fixation durations $F(1,37) = 25.61$, $p < .001$, gaze durations $F(1,37) = 43.01$, $p < .001$, go-past reading times $F(1,37) = 14.84$, $p < .001$, and total reading times $F(1,37) = 18.05$, $p < .001$ were exhibited for high-frequency compared to infrequent words.

There was a significant main effect of length for the late eye movement measures. Specifically, as seen in Table 39, shorter, go-past times $F(1,37) = 5.27$, $p = .011$, and total reading time $F(1,37) = 15.08$, $p < .001$, were exhibited for short compared to long words. There was no significant difference in first fixation durations ($F(1,37) = 0.11$, $p = .741$), gaze durations ($F(1,37) = 0.29$, $p = .592$), or total reading times ($F(1,37) = 3.43$, $p = .072$) between short and long words.

There were no significant length by frequency interactions for early eye movement measures, nor for total reading time, however these interactions were significant for go-past times. Specifically, as seen in Figures 47-50, there was no significant interaction for first fixation durations ($F(1,37) = 0.48$, $p = 827$), gaze durations ($F(1,37) = 0.80$, $p = .376$) or go-past times (*F*(1,37) = 5.80, *p* = .021) with the corrected Bonferroni alpha of 0.013. There were significant length by frequency interactions for total reading times *F*(1,37) = 6.55, *p* = .013. These interactions indicate that for go-past times, there were no frequency effects for short words, and no length effects for high-frequency words, but there were length effects for low-frequency words.

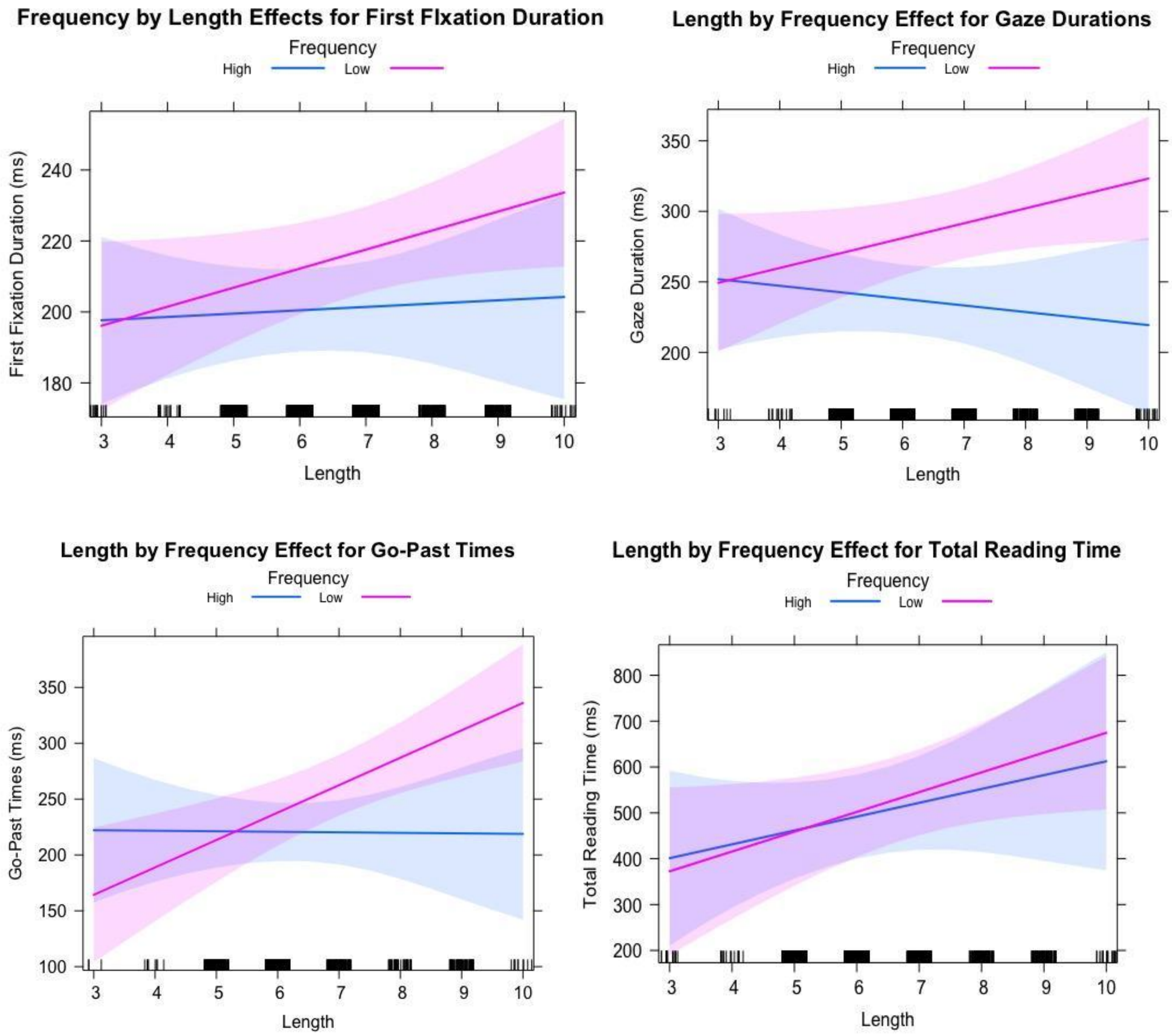

Figure 47, 48, 49, and 50. Length and Frequency effects on Eye Movement Measures for Spanish-English Bilingual Readers Reading in English

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5.3.4.3 Comparisons between Spanish-English Bilinguals Reading in their L1 vs. their L2

Sentence-Level Eye Movement Measures

Mean sentence level measures are tabulated in Table 40. To test the differences in whole-sentence reading patterns between Spanish-English bilinguals reading in their L1 (measured in *Experiment 6*, Chapter-4) versus their L2, a set of 4 paired samples T-Tests with Bonferroni corrected alphas of .013 were computed on average fixation duration, total reading time, total number of fixations, and total number of backward saccades. We expected that Spanish-English bilingual readers would exhibit relatively shorter fixation durations but more fixations, and regressions while reading in Spanish compared to reading in English.

Spanish-English bilinguals exhibited significantly more fixations per sentence $t(37) = 7.85$, $p < .001$ while reading in English ($M = 15.05$, $SD = 4.02$) than reading in Spanish ($M = 11.79$, $SD = 3.38$). Fixation durations were also significantly shorter $t(37) = 6.85$, $p < .001$ while the bilinguals read in Spanish ($M = 183.63$, $SD = 12.42$) versus reading in English ($M = 199.16$, $SD = 17.78$). Spanish-English bilinguals had significantly more regressions $t(31) = 4.62$, $p < .001$ while reading in English ($M_{backward} = 5.19$, $SD_{backward} = 1.92$) than while reading in Spanish ($M_{backward} = 4.39$, $SD_{backward} = 1.50$). Spanish-English bilinguals had significantly longer average reading times per sentence $t(37) = 8.58$, $p < .001$ while reading in English ($M = 3606.70$, $SD = 981.69$) compared to reading in Spanish ($M = 2668.35$, $SD = 759.78$).

Table 40. Mean Eye-Movement Measures Across Sentences between Spanish-English bilinguals reading in Spanish and in English

Measure Mean (SD)	Fixation Count	Regression Count	Average Fixation Duration (ms)	Total Reading Time (ms)
Spanish Reading	11.78 (3.3)	4.38 (1.49)	184.33 (12.09)	2665.26 (739.95)

English Reading	15.02 (3.88)	5.18 (1.89)	200.34 (17.99)	3643.49 (978.17)

Word-Level Measures

To compare word-level reading strategies between bilingual reading strategies in L1 versus L2, a 2 (Length: Short vs. Long) x 2 (Frequency: High vs. Low) x 2 (Language: L1 vs L2) within-subjects ANOVA was calculated for first fixation durations, gaze durations, go-past times, and total reading times with Bonferroni corrected alphas of 0.013. Only main effects of language and significant interactions are reported. It was expected that there would be larger length effects, but smaller frequency effects when these readers read in Spanish, compared to English.

First Fixation Durations There was a significant main effect of language for first fixation durations $F(1,37) = 22.35$, $p < .001$. As seen in Figure 51, Bilingual readers had faster first fixation durations while reading in their Spanish ($M = 188.43$, $SD = 19.19$) compared to reading in English ($M = 202.71$, $SD = 28.06$).

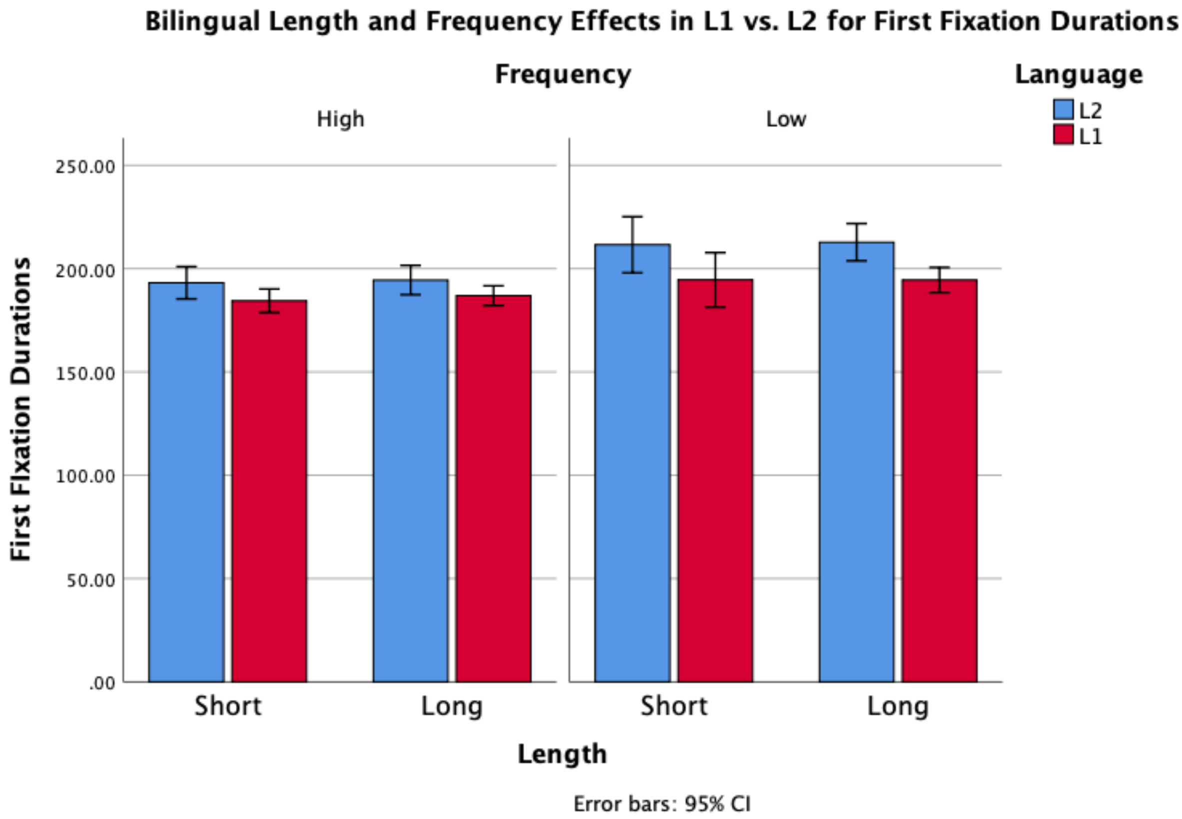

Figure 51. Length and Frequency Effects for First Fixation Durations for Bilinguals Reading in their L1 vs. L2

Gaze Durations There was a main effect of language for gaze durations $F(1,37) = 45.91$, $p < .001$. As seen in Figure 52, bilingual readers exhibited significantly longer gaze durations in English ($M = 286.96$, $SD = 69.78$) compared to Spanish ($M = 228.12$, $SD = 60.13$).

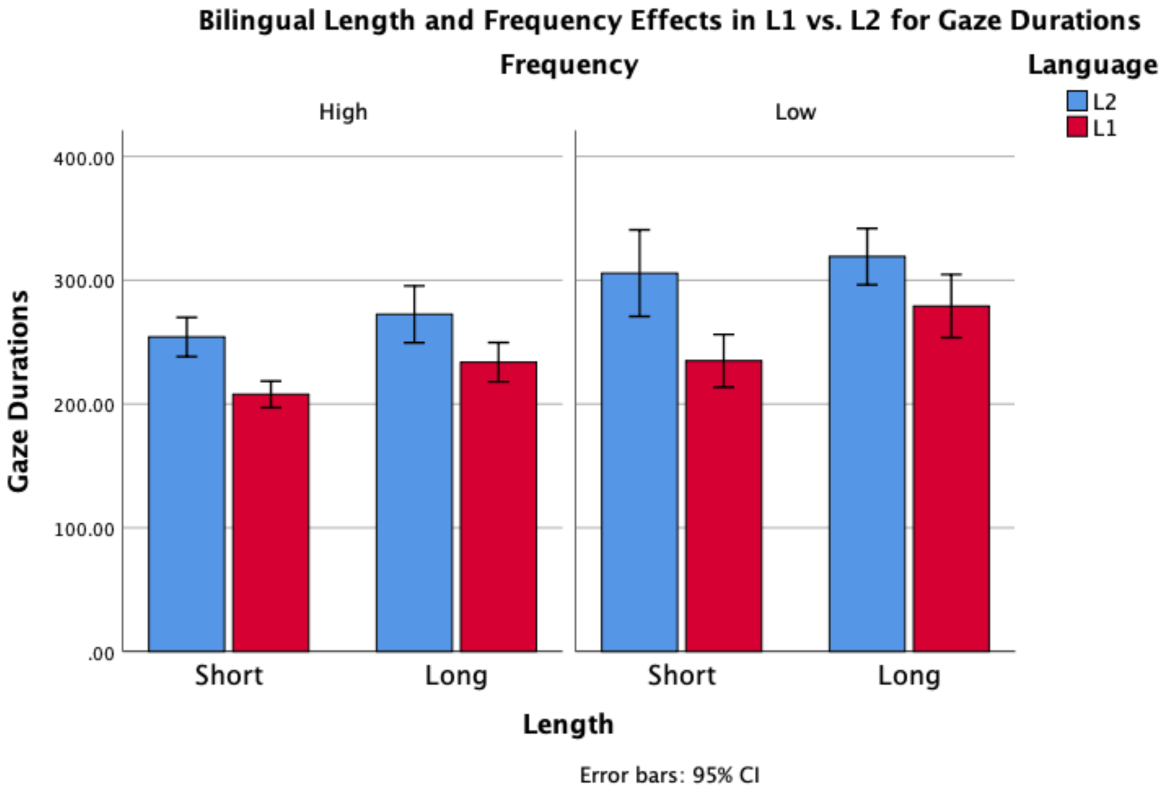

Figure 52. Length and Frequency Effects for Gaze Durations for Bilinguals Reading in their L1 vs. L2

Go-Past Times A main effect of language was found for go-past times $F(1,37) = 21.26$, $p < .001$. Results indicated that bilingual readers had significantly longer go-past times while reading in English ($M = 277.04$, $SD = 96.71$) compared to reading in Spanish ($M = 266.17$, $SD = 72.81$).

There was a significant length x frequency interaction for go-past times, $F(1,37) = 7.144$, $p < .01$. As seen in Figure 53, there was no frequency effect for short words, but there was a frequency effect for long words high-frequency short words did not have faster go-past times than low-frequency short words ($M_{HF} = 222.502$, $SD_{HF} = 56.43$;. $M_{LF} = 235.25$, $SD_{LF} = 106.18$), however, high-frequency long words had longer go-past times than low-frequency long words ($M_{HF} = 243.41$, $SD_{HF} = 70.09$;. $M_{LF} = 298.49$, $SD_{LF} = 100.15$).

There was a significant language x frequency interaction $F(1,37) = 6.03$, $p < .01$ for go-past times. Indicating there was a smaller frequency effect for readers reading in Spanish ($M_{HF} =$

214.03, SD_{HF} = 50.98;. M_{LF} = 241.33, SD_{LF} = 91.44) compared to reading in English (M_{HF} = 254.42, SD_{HF} = 71.54;. M_{LF} = 300.74, SD_{LF} = 113.26).

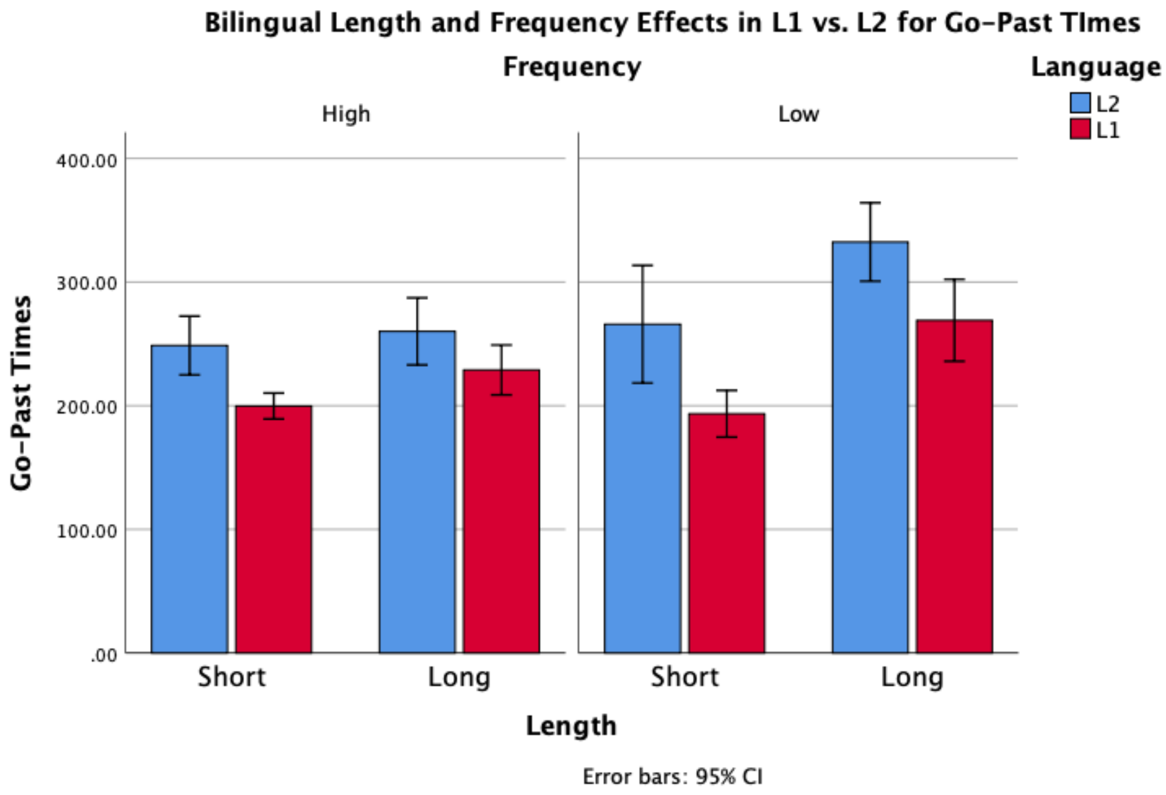

Figure 53. Length and Frequency Effects for Go-Past Times for Bilinguals Reading in their L1 vs. L2

Total Reading Times There was a main effect of language for total reading times $F(1,37) = 98.73$, $p < .001$ such that bilingual readers had longer total reading times while reading in English (M = 473.48, SD = 156.78) compared to reading in Spanish (M = 338.58, SD = 131.14).

There was a significant length x frequency effect $F(1,37) = 19.28$, $p < .001$. As seen in Figure 54, there was no length effect for high-frequency words, but there was a length effect for low-frequency words. High-frequency short words did not have significantly faster total reading times than high-frequency long words (M_{short} = 340.63, SD_{short} = 123.31;. M_{long} = 374.65, SD_{long} = 115.21), however, low-frequency short words did have significantly faster total reading times than low-frequency long words (M_{short} = 404.29, SD_{short} = 184.05; M_{long} = 460.96, SD_{long} = 168.65).

There was a significant language x frequency interaction for total reading times $F(1,37) = 5.19$, $p < .01$, such that frequency effects were smaller for bilinguals reading in Spanish (M_{HF} = 292.95, SD_{HF} = 82.25;. M_{LF} = 353.70, SD_{LF} = 124.98) compared to reading in English (M_{HF} = 432.57, SD_{HF} = 113.65;. M_{LF} = 516.34, SD_{LF} = 183.19).

There was a significant language x length interaction $F(1,37) = 13.12$, $p < .01$, indicating that length effects were larger for bilingual readers reading in Spanish (M_{short} = 281.17, SD_{short} = 85.12;. M_{Long} = 383.14, SD_{Long} = 143.24) compared to English (M_{short} = 455.35, SD_{short} = 166.01; M_{Long} = 490.78, SD_{Long} = 146.61).

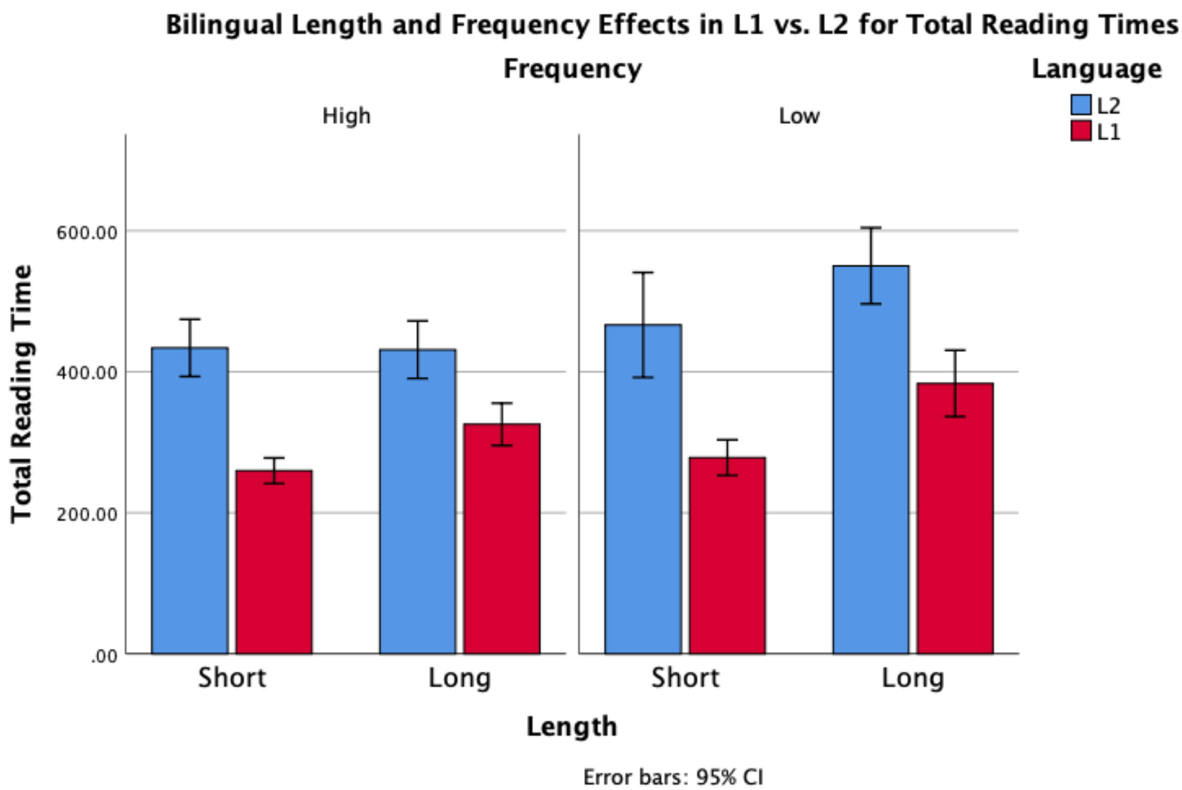

Figure 54. Length and Frequency Effects for Total Reading Times for Bilinguals Reading in their L1 vs. L2

5.3.4.4 Group comparisons for Sentence Level Measures between Native English readers without dyslexia vs Spanish-English bilingual readers in English

Sentence-Level Eye-Movement Measures

To compare sentence-level reading strategies between bilingual Spanish-English readers reading in English and readers with (*Experiment 4*, Chapter-3) and without dyslexia (*Experiment 2,* Chapter-2), a one-way ANOVA was computed for fixation count, average fixation duration, regression count and total reading time with Bonferroni corrected alphas of 0.013. Only significant results are reported.

Fixations There was a significant difference between these groups for the total number of fixations $F(2,98) = 7.57$, $p < .01$. As tabulated in Table 41, Bonferroni post-hoc tests revealed that Spanish-English bilinguals did not exhibit significantly more fixations on average than did the native English readers, ($p = .095$), and did not exhibit significantly fewer fixations than the readers with dyslexia, ($p = .195$). However, the difference between the native English readers with and without dyslexia was significant $p < .01$.

Saccades There was also a significant difference in average regression count between these groups $F(2,98) = 7.88$, $p < .01$. As tabulated in Table 41, Bonferroni post-hoc tests revealed that Spanish-English bilinguals did not exhibit significantly fewer regressions on average than did the native English readers, ($p = .999$). However, the dyslexic readers exhibited significantly more regressions than both the English typical readers $p < .001$ and bilingual readers $p < .001$.

Average Total Reading Time There was also a significant difference in average total reading times between these groups $F(2,98) = 8.19$, $p < .01$. As tabulated in Table 41, Bonferroni post-hoc tests revealed that Spanish-English bilinguals did not exhibit significantly longer total reading times on average than did the native English readers, ($p = .999$). However, the dyslexic readers exhibited significantly longer total reading times than both the English typical readers $p < .001$ and bilingual readers $p < .01$.

Table 41. Mean Eye-Movement Measures Across Sentences between Spanish-English bilinguals and English monolinguals with and without Dyslexia

Measure Mean (SD)	Fixation Count	Regression Count	Average Fixation Duration (ms)	Total Reading Time (ms)
English Typical Readers	13.47 (2.99)	5.38 (1.39)	204.67 (19.58)	3510.65 (782.57)
English Dyslexic Readers	17.41 (1.54)	7.02 (0.76)	202.51 (18.50)	4513.19 (570.23)
Spanish-English Bilinguals	15.02 (3.88)	5.18 (1.89)	200.34 (17.99)	3643.49 (978.17)

Word-Level Eye-Movement Measures

To compare local reading strategies between Spanish-English bilingual readers (*Experiment 4*, Chapter-3) and without dyslexia (*Experiment 2,* Chapter-2), A 2 (Length: Short vs. Long) x 2 (Frequency: High vs. Low) x 3 (Group: English dyslexic vs. English non-dyslexic vs. bilingual) between-subjects ANOVA was calculated for first fixation durations, gaze durations, go-past times, and total reading times again with Bonferroni corrected alphas of .013. Only main effects of group and significant interactions are reported.

First Fixation Durations There was a significant main effect of group for first fixation durations $F(2,369) = 3.00$, $p < .01$. As seen in Figure 55, bonferroni post-hoc analyses indicated that bilingual readers had faster first fixation durations ($M = 202.72$, $SD = 28.06$) compared to English readers without dyslexia ($M = 210.48$, $SD = 30.35$) $p < .05$, however they did not exhibit significantly shorter first fixation durations from English dyslexic readers ($M = 209.14$, $SD = 25.33$) ($p = .593$).

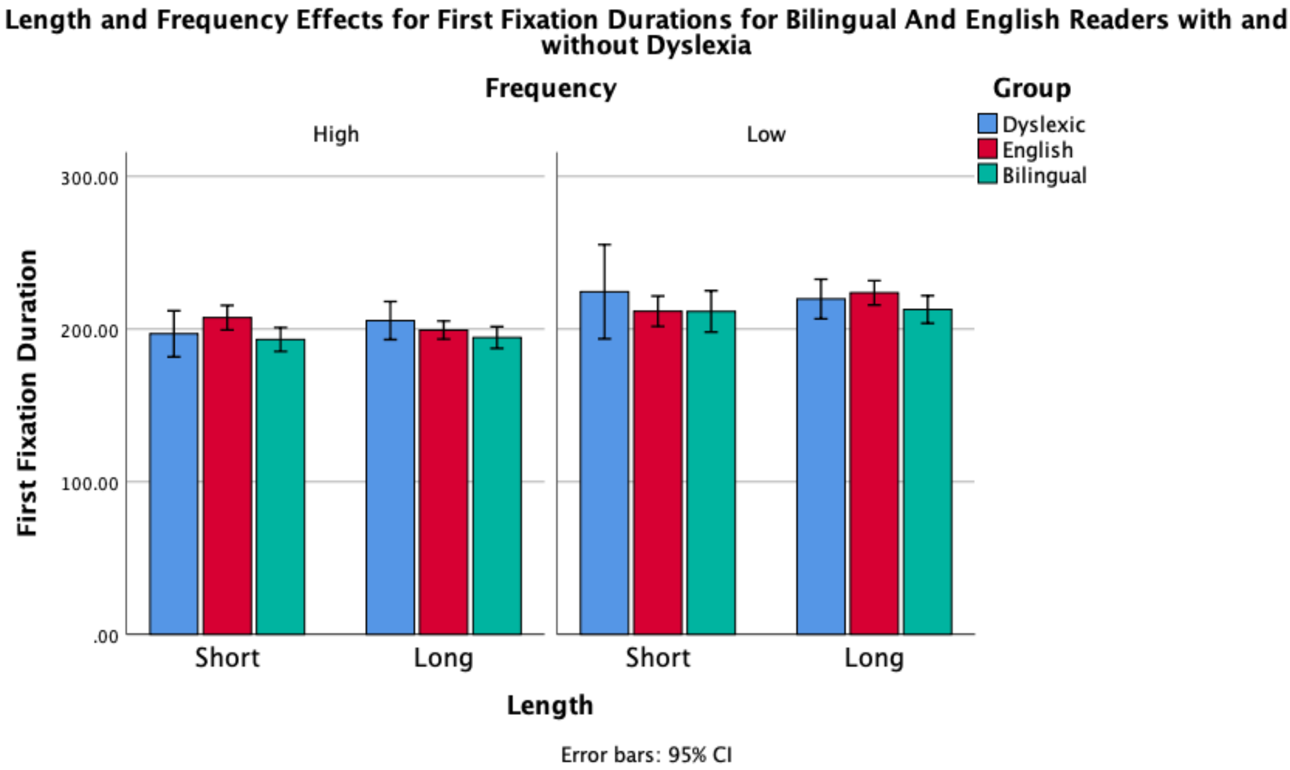

Figure 55. Length and Frequency Effects for First Fixation Durations for Bilinguals and Monolingual English Readers with and without Dyslexia

Gaze Durations There was a main effect of group for gaze durations $F(2,369) = 8.04$, $p < .001$. As seen in Figure 56, bonferroni post hoc comparisons indicated that bilingual readers exhibited significantly longer gaze durations ($M = 286.96$, $SD = 69.78$) compared to English readers without dyslexia ($M = 262.04$, $SD = 56.85$) $p < .001$, but not compared to English readers with dyslexia ($M = 265.37$, $SD = 45.02$) ($p = .099$).

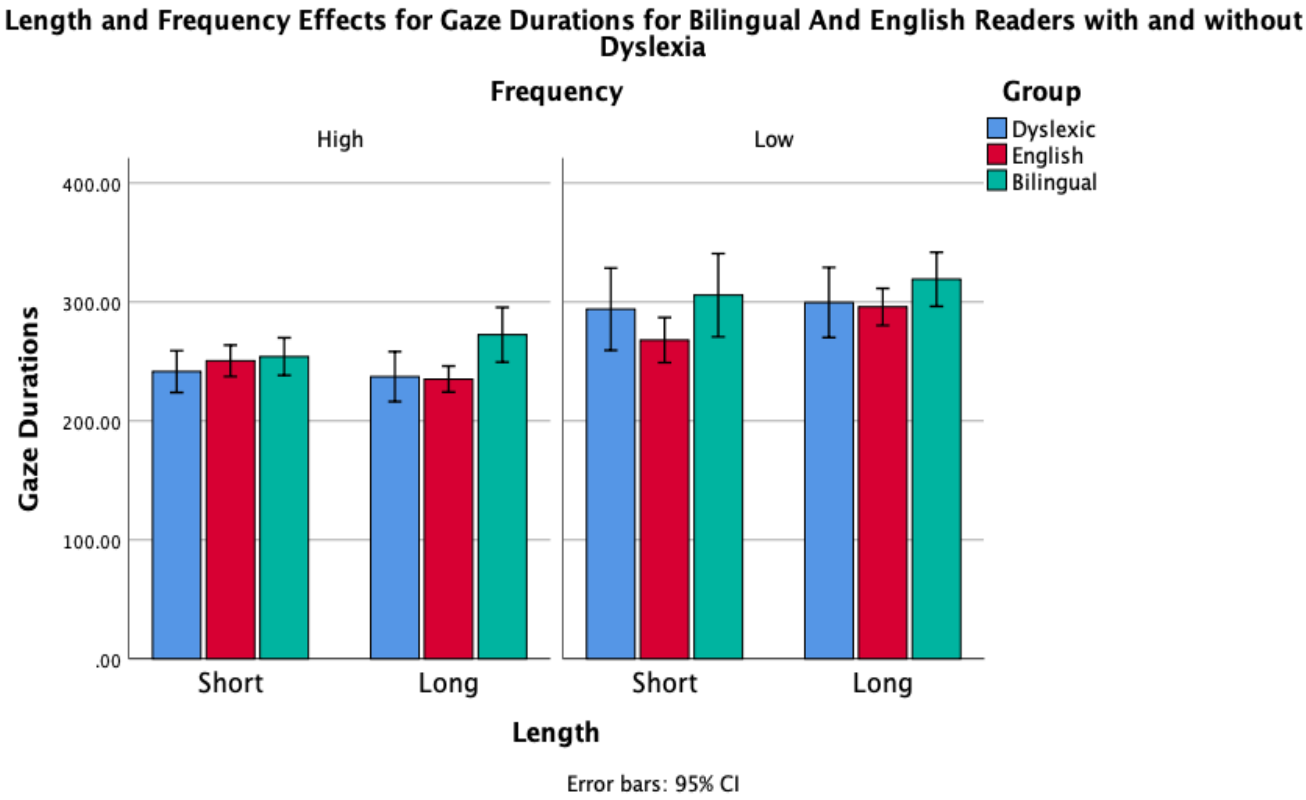

Figure 56. Length and Frequency Effects for Gaze Durations for Bilinguals and Monolingual English Readers with and without Dyslexia

Go-Past Times A main effect of group was found for go-past times $F(2,369) = 8.95$, $p < .001$. Bonferroni post hoc comparisons indicated that bilingual readers had significantly longer go-past times ($M = 277.04$, $SD = 96.71$) than both English readers with dyslexia ($M = 235.40$, $SD = 57.99$) $p < .01$ and English readers without dyslexia ($M = 243.99$, $SD = 75.78$) $p < .001$.

There was a significant length x frequency interaction for go-past times, $F(1,369) = 12.94$, $p < .001$. As seen in Figure 57, there was no length effect for high-frequency words, but there was a length effect for low-frequency words. High-frequency short words did not have significantly faster go-past times than high-frequency long words ($M_{short} = 230.15$, $SD_{short} = 66.12$;. $M_{Long} = 237.45$, $SD_{Long} = 59.14$), however, low-frequency short words did have significantly faster go-past times than low-frequency long words ($M_{short} = 241.06$, $SD_{short} = 97.42$; $M_{long} = 307.22$, $SD_{long} = 84.68$).

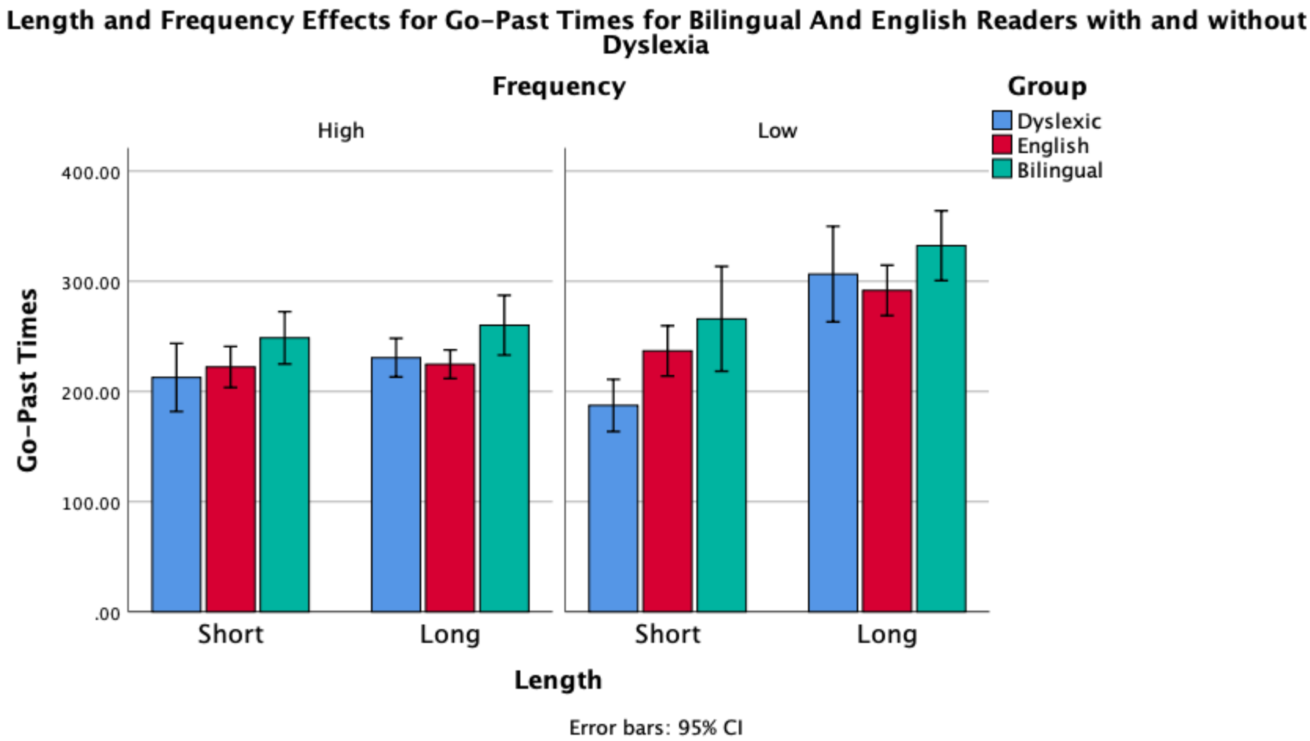

Figure 57. Length and Frequency Effects for Go-Past Times for Bilinguals and Monolingual English Readers with and without Dyslexia

Total Reading Times There was no main effect of group for total reading times ($F(2,369) = 2.38$, $p = .094$) such that bilingual readers ($M = 473.48$, $SD = 156.78$), English readers with dyslexia ($M = 500.23$, $SD = 127.91$) and English readers without dyslexia ($M = 453.14$, $SD = 143.86$) did not differ significantly in their total reading times.

There was a significant length x frequency effect $F(1,369) = 4.28$, $p < .01$. As seen in Figure 58, there was no length effect for high-frequency words, but there was a length effect for low-frequency words. High-frequency short words did not have significantly faster total reading times than high-frequency long words ($M_{short} = 414.85$, $SD_{short} = 121.35$;. $M_{long} = 450.71$, $SD_{long} = 125.09$), however, low-frequency short words did have significantly faster total reading times than low-frequency long words ($M_{short} = 442.09$, $SD_{short} = 158.42$; $M_{long} = 552.42$, $SD_{long} = 145.35$).

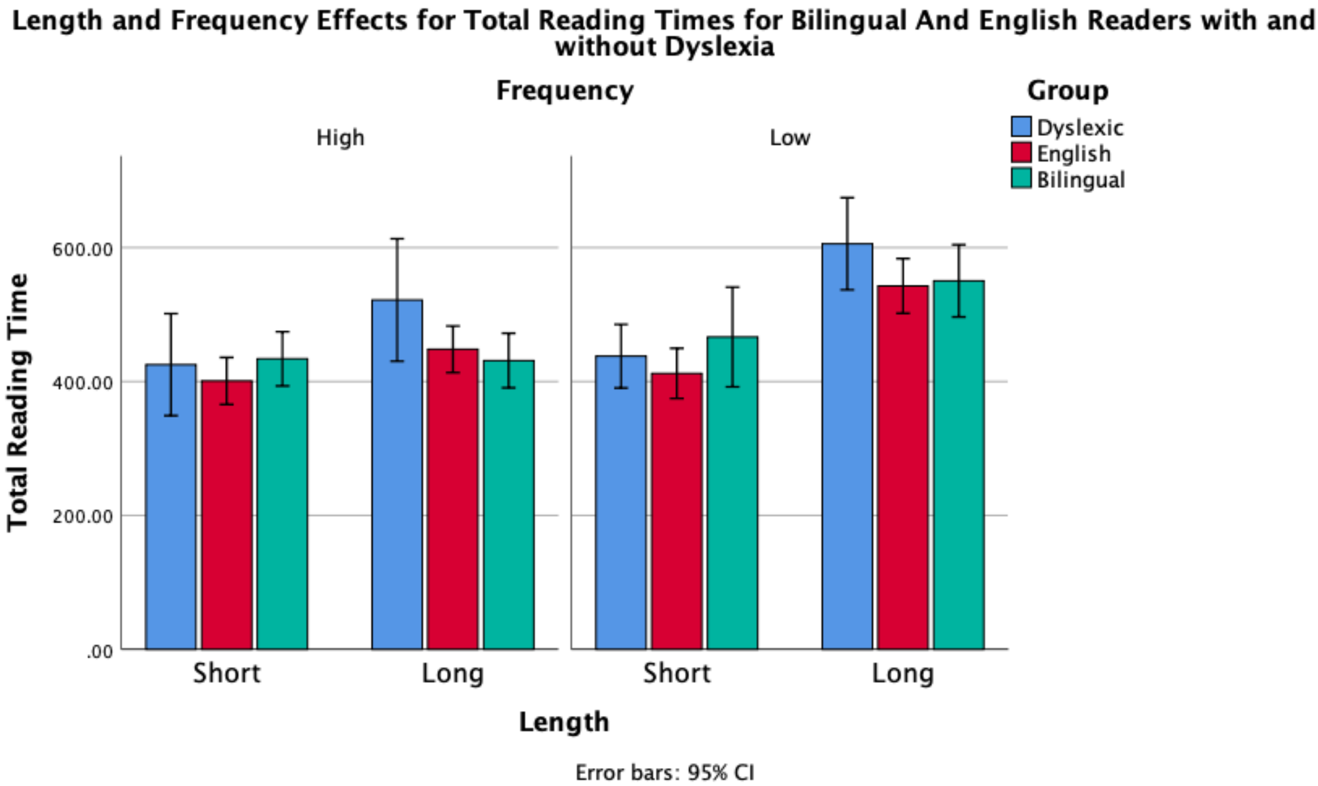

Figure 58. Length and Frequency Effects for Total Reading Times for Bilinguals and Monolingual English Readers with and without Dyslexia

5.3.4.5 Correlations Between Eye Movement Patterns and Behavioural Measures for Spanish-English Bilinguals in English

To test whether the scores from the WMLS III were related to eye movement patterns, a series of correlations between each eye movement measure and each language ability measure from the WMLS III have been conducted. Only significant correlations were reported.

Sentence-Level Measures

First, the language scores were correlated with the whole sentence eye movement scores (average fixation duration, total fixation count, regression count and total reading time) with Bonferroni corrected alphas of 0.013. There were no significant correlations between the WMLS III measures and any of the sentence-level eye movement measures.

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Word-Level Measures

Next, the language ability scores and eye movements measured at the word-level (first fixation duration, gaze duration, go-past time, and total reading time) were correlated with Bonferroni corrected alphas of 0.003.

Decoding: There was a significant negative correlation between decoding scores and total reading times $r(38) = -.42$, $p < .001$ for low-frequency short words.

Language Comprehension: There was a significant negative correlation between language comprehension scores and total reading times $(38) = -.40$, $p < .001$ for low-frequency short words.

Vocabulary Knowledge: No significant correlations were found.

Reading Comprehension: There were significant negative correlations between reading comprehension scores and gaze durations $r(38) = -.40$, $p < .001$ for low-frequency short words.

5.3.5 Discussion

The goal of *Experiment 7* was to test reading strategies of Spanish-English bilinguals reading in their L2 (English) as measured by eye movements during sentence comprehension. Of further interest was a comparison of these with patterns of reading abilities described in the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990) that were measured offline. These comparisons offer a more in-depth view of online reading strategies as measured by eye movement patterns and how they may be driven by offline measured reading abilities. These investigations offer further insight into bilingual processes during reading and findings could have potential implications in detecting problems from arising from either reading or language difficulties in bilingual groups reading in a second language.

The current chapter also compared these eye movement strategies with those of native-English monolinguals with and without dyslexia, measured in *Experiment 1* (Chapter-2) and

3 (Chapter-3) and the same Spanish-English bilinguals measured in *Experiment 5* (Chapter-4) reading in their L1 (Spanish). Such comparisons allow an examination of the similarities and differences of reading strategies for native readers of an inconsistent orthography with bilinguals who read in both an inconsistent and a consistent orthography. These findings were interpreted within the context of the ODH (Kats & Frost, 1992) and the Psycholinguistic Grain Size Theory (Ziegler & Goswami, 2005) to gain a better understanding of how orthographic depth of languages may drive reading strategies.

It was expected (H*ypothesis 1*) that Spanish-English bilinguals reading in English would demonstrate similar length and frequency effects observed in the native-English readers from *Experiment 1* (Chapter-2). In the current sample, the bilinguals reading in their L2 both early and late eye movement measures were found to be sensitive to frequency effects. Word length appears to have affected only the late eye movement measures, however significant interactions between length and frequency indicated that in the case of go-past times, there were no frequency effects for short words, and no length effects for high-frequency words. Similar patterns were also found for native-English readers, but not for the same bilingual readers as they read in Spanish.

Compared to reading in Spanish, the current sample of bilinguals exhibited more frequent and longer fixations, more frequent regressions, and longer total reading times when reading sentences in English. These findings supported *Hypothesis 2*. Bilinguals also had faster first fixation durations, gaze durations, go-past times, and total reading times while reading in Spanish compared to English. It was expected (*Hypothesis 3*) that L1 reading in Spanish would demonstrate larger length effects, but smaller frequency effects than L2 reading in English for each eye movement measure. This hypothesis was partially supported. The size of the length and frequency effects were not significantly different for first fixation durations. For gaze durations, the size of frequency effects also did not significantly differ, but length effects were larger for the bilinguals reading in their L1. For go-past times, frequency effects were significantly smaller in the L1 compared to the L2 with no difference in length effects. Finally, for total reading times, frequency effects were significantly smaller, but length effects were significantly larger for bilinguals reading in Spanish, compared to reading in English.

It was expected (*Hypothesis 4*) that bilinguals will largely be able to adapt their reading strategies when reading in English and thus will deploy reading strategies similar to their native English peers. To this end, it was expected that the sizes of length and frequency effects would not significantly differ between the groups. However, given that these bilinguals scored lower on reading tasks compared to native English readers, and showed evidence of skill transfer in *Experiment 7*, we also expect that they will transfer some reading strategies from Spanish given that it is their dominant language. Specifically, since Spanish language comprehension made a direct contribution to English reading comprehension and correlated significantly with first fixation durations in L1 reading in *Experiment 6* (Chapter-4), it was expected that first fixation durations would significantly differ. This hypothesis was largely supported by the data. Spanish-English bilinguals reading in English exhibited comparable sentence-level measures of reading (e.g., fixation durations, fixation counts, regression counts and total reading times) as English monolingual readers without dyslexia. Indicating that the bilinguals were largely able to adapt their reading strategies. Further, the size of the length and frequency effects were not significantly different for any of the eye movement measures. However, some differences in eye-movements between Spanish-English bilingual readers and monolingual English readers without dyslexia were observed at the word-level which may be indicative of some transfer.

Similar to predictions from the native English readers in *Experiment 2* (Chapter-2), it was expected (*Hypothesis 5)* that eye movement measures such as fixation count and fixation duration considered to reflect decoding strategies (e.g.,Rayner, Slattery, Drieghe, & Liversedge, 2011) should significantly correlate with the decoding scores measured in *Experiment 7*. Total reading time and regressions on the other hand should correlate with higher order language measures such as vocabulary, language comprehension and reading comprehension (e.g., Liversedge, Paterson, & Pickering, 1998; Rayner, 1998). For word-level eye movements, since the behavioural data from *Experiment 7* demonstrated that language comprehension skills were better predictors of reading comprehension than decoding, it was predicted that late eye movement measures of reading measured at the word-level (i.e., go-past time and total reading time, thought to reflect higher order language skills) would be better predictors of reading comprehension abilities than early eye movement measures of reading in this sample (*Hypothesis 6*).

Findings did not support Hypothesis *5*, as there were no significant correlations between the SVR component skills and the sentence-level measures, however, all the SVR components, but not vocabulary did significantly correlate with both early and late measures of word-level reading which partially supported *Hypothesis 6*.

Each of these results will be discussed in further detail below.

5.3.4.1 Eye Movement Strategies Employed by Spanish-English Bilinguals Reading in English (L2)

Sentence-Level Measures

Sentence-level measures were analysed from average reading strategies across the sentences. Fixation count, fixation duration, regression count, and average total reading time were analysed. In the current sample, average fixation durations (200.34 ms) were within the range typically observed in monolingual English skilled adult readers' average (200–250 ms; Rayner, 1998; Rayner et al., 2006; Rayner, Sereno, Morris, Schmauder, & Clifton, 1989). The proportion of regressive saccades in the current sample was 34%, which was higher than the 10%-15% observed by Rayner (1998). However, the current observation of 34% was also closer to the proportions of saccades that have been reported for low-skilled adult readers (e.g., 35% in Barnes & Kim, 2016; 30% in Barnes, Kim, Tighe & Vorstius, 2017). These findings make sense given that the measured reading skills in *Experiment 5* (Chapter-

4) were significantly poorer than the English monolingual sample. Regressions occur when the reader requires further processing of texts that were previously unprocessed or not understood (Starr & Rayner, 2001). Thus, the current sample of Spanish-English bilinguals presumably needed to re-fixate on previous words to resolve misunderstandings more frequently than the skilled monolingual English readers.

These eye movements of Spanish-English bilinguals reading in English (L2) were significantly different from the eye movements they exhibited when reading in their native Spanish. Specifically, compared to reading in Spanish, the current sample of bilinguals exhibited more frequent and longer fixations, more frequent regressions, and longer total reading times when reading sentences in English. These findings are consistent with eye movement research with bilinguals generally suggests that bilingual readers make shorter fixations, longer saccades, and fewer regressions in their dominant language (Altarriba, Kambe, Pollatsek, & Rayner, 2001; Altarriba, Kroll, Sholl, & Rayner, 1996; Balling, 2013; Bultena, Dijkstra, & van Hell, 2014; Friesen & Jared, 2007; Hoverstern & Traxler, 2015; Titone, Libben, Mercier, Whitford, & Pivneva, 2012).

However, these eye movements did not differ significantly from native-English readers. Taken together these findings would suggest that the current sample of proficient bilinguals were able to adjust their sentence-level strategies to meet the demands of the English orthography. Further, the Spanish-English bilinguals also exhibited significantly fewer fixations and regressions and shorter total reading times compared to the native English readers with dyslexia. These results imply that despite more experience reading in a consistent orthography which requires different reading strategies, proficient bilinguals may be able adjust their reading strategies without suffering the same consequences as dyslexic readers who struggle with the phonological inconsistencies of the English language. These findings perhaps have further implications for dyslexic readers suggesting that orthography may perpetuate phonological difficulties associated with dyslexia, but they may not necessarily largely stem from orthographic inconsistency.

Word-Level Measures

The word-level measures were analysed in terms of length and frequency effects to investigate the time-course of reading strategies for Spanish-English bilinguals reading in English.

To review, early eye movement measures such as first fixation duration and gaze duration are assumed to reflect initial lexical access and early integration of information. These eye movement measures may be particularly sensitive to lexical information such as misspellings (e.g., Pagán, Blythe & Liversedge, 2021), but also may be sensitive to phonological information (Rayner et al., 1998; Rayner et al., 2003; Slattery, Pollatsek & Rayner, 2006; Sparrow & Miellet, 2002). In contrast, late measures such as go-past time and total reading time are assumed to reflect higher order processes such as semantic integration, revision, and ambiguity resolution (Liversedge, Paterson, & Pickering, 1998; Rayner, 1998; Rayner, 2009). For example, regressions and second-pass eye movement measures such as go-past times indicate a reanalysis of text that has already been fixated upon at least once. Thus, the occurrence of these eye movements indicates some difficulty with the text and reflect the cost (in time) of overcoming these difficulties (Clifton, Stuab & Rayner, 2007).

Both early and late eye movement measures were found to be sensitive to frequency effects as indexed by shorter first fixation durations, gaze durations, go-past times, and total reading time for high-frequency compared to low-frequency words. On the other hand, word length effects were only found in late eye movement measures. However significant interactions between length and frequency indicated that in the case of go-past times, there were no frequency effects for short words, and no length effects for high-frequency words. Similar patterns were also found for native-English readers (*Experiment 2 in Chapter-2)*, except for the findings that there were interactions between length and frequency for all eye movement measures. In the current sample, there was only a significant interaction for go-past times. Inspection of the graphs however indicate a similar trend for fixation durations, gaze durations, and go-past times where frequency did not affect short words, and length did not affect high-frequency words. However, these interactions were not significant in the current sample. These patterns of length and frequency effects for Spanish-English bilinguals reading in their L2 also differed from those found when they read in their L1 in *Experiment 5* (Chapter-4). Recall that in *Experiment 5* this same sample of bilinguals demonstrated length and frequency effects for both early and late eye movement measures with interactions that suggested there were length effects for high and low-frequency words, but only frequency effects for long words.

Taken together these effects found for Spanish-English bilinguals initially suggest that these readers are adjusting their strategies from those used to read in Spanish and are demonstrating similar patterns to native English readers. These findings are consistent with previous research suggesting that different processes are used when bilinguals read their first language compared to their second (e.g., Brignoni-Perez, Jamal & Eden, 2020; Jamal, Piche, Napoliello, Perfetti & Eden, 2012). Thus, these patterns can be interpreted in the same way they were interpreted for English native readers without dyslexia. That is, it appears as though the bilinguals are employing a lexical reading strategy that processes larger grains of information at a time, rather than employing a sub-lexical reading strategy to read in English. Given that these bilingual readers did not demonstrate significantly slower reading times from the English native readers, these findings indicate that these strategies are being employed sufficiently. Further, similar to the time-course of the reading strategies for native English readers, frequency effects appear to be processed during early lexical access whereas length effects are processed later during the reading process. Such effects are consistent with previous literature that has demonstrated robust frequency effects for readers of English (e.g., Ashby, Rayner & Clifton, 2005; Blythe et al., 2009; Inhoff and Rayner 1986). Similarly, length effects observed in the only late eye movement measures of reading (go-past times and total reading times) indicate that perhaps frequency information is processed in early lexical integration, while word length affects only the later processes. These results are consistent with those reported by Rayner, Sereno, and Raney (1996) who found that total reading time and re-fixations increased as word length increased. Hyona and Olsen (1995), and later Joseph and colleagues (2013) similarly did not find length effects for first fixation durations, but they did find them for gaze durations and second pass reading times.

These findings are consistent with the DRC model of reading (Coltheart, Rastle, Perry, Langdon & Ziegler, 2001). Early eye movement measures which reflect early lexical access may be sensitive to frequency effects since low-frequency words may slow the sub-lexical route once the lexical route fails to find a reliable match in the lexicon. However, since the sub-lexical route is notoriously unreliable in English, this may have affected the early eye movement measures associated with phonological processing and decoding. These early measures may not have been able to resolve the discrepancy in the current sample of readers, and thus, later measures of lexical access may have also been slowed to allow for conflict resolution. Specifically, the go-past eye movement measure may reflect the cost of overcoming some difficulty with the first pass since it includes the time the eyes spent in the first pass reading as well as second pass readings (Clifton, Stuab & Rayner, 2007). Total reading time reflects all first pass and second pass measures and thus would have been slowed as well.

Following this account, these findings would also support the weak version of the ODH (Katz & Frost, 1992) which posits that both the sub-lexical and lexical route are available to all readers. These findings also support the Psycholinguistic Grain Size Theory (Ziegler & Goswami, 2005) which argues that readers are confronted with three problems: availability, consistency, and granularity of spelling-to-sound mappings. Reading strategies depend on the efficiency with which these problems can be conquered by readers, which will vary across languages. Based on these findings, it would appear as though proficient Spanish-English bilinguals are able to overcome the consistency problem of English and apply appropriate strategies to read efficiently.

5.3.4.2 Comparisons between Spanish-English Bilinguals Reading in the L1 vs their L2.

Although the above findings suggest a different pattern between bilinguals reading in their L1 versus their L2, the current study aimed to quantify this difference using direct comparisons. The results of these analyses indicated that compared to reading in Spanish, the current sample of bilinguals exhibited overall slower first fixation durations, gaze durations, go-past times, and total reading times while reading in English.

Length effects

Mean eye movement measures indicated that the length effect was larger when bilinguals read in Spanish compared to English, however, this was only significant for gaze durations and total reading times. It was expected that Spanish-English bilinguals would show larger length effects in Spanish compared to English since the sub-lexical process is more reliable in Spanish than English. However, the sub-lexical process is more sensitive to length than to frequency because it is a slower serial-decoding process compared to faster lexical procedure. These results may indicate that perhaps the role of first fixation durations is to process frequency information, once processed, length may affect first pass reading durations (gaze durations) for Spanish readers who are processing longer word sub-lexically, but not when reading in English because it may be more efficient at this point to employ a lexical reading strategy. However, larger length effects may not necessarily affect refixation time as the bilingual readers reading in Spanish should be able to reliably process words sub-lexical without much conflict resolution. However, if gaze durations are slowed, this would likely also slow total reading times.

Since length effects were not significantly larger in Spanish compared to English for all eye movement measures, perhaps this indicates some degree of cross-linguistic transfer. This would be consistent with previous research that reported evidence of transfer (e.g.,Koda, 2007; Verhoeven, 1990; Pritchard & O'Hara, 2008; Royer & Carlo, 1991; Riccio et al., 2001; Lemhöfer et al., 2008; Relyea & Amendum, 2020; Deacon, Chen, Luo, & Ramirez, 2013) and may also support models of non-selective lexical access (Dijkstra & Van Heuven, 2002).

Frequency effects

As expected, frequency effects were smaller in all eye movement measures in Spanish compared to when the bilinguals were reading in English. However, this effect was only significant for the late eye movement measures. These findings may indicate that frequency effects are processed at similar rates in early eye movement measures, but once they are processed, frequency will continue to affect later eye movement measures when bilinguals are reading in English because they are likely employing a lexical strategy and still processing larger grains. These eye movement measures would be affected by frequency to a lesser degree in Spanish however, because likely they are still relying more heavily on serial decoding sub-lexical strategies which would not be slowed by frequency. These findings would support the ODH and the PGST.

As previously discussed however, it is also possible that larger frequency effects for bilinguals reading in their L2 compared to reading in their L1 is a result of poorer language proficiency in the L2 compared to the L1. These findings were reported by Whitford and Titone (2012; 2015; 2017) found that English-French bilinguals and French-English bilingual adults' with less L2 reading experience exhibited significantly larger frequency effects in their L2 compared to their L1 which were apparent in first fixation durations, gaze durations, go-past times, and total reading times.

However, some researchers have argued that larger length and frequency effects in an L2 compared to an L1 is just a consequence of what they termed the base-rate effect (Butler & Hains, 1979; Faust et al., 1999; Yap et al., 2012). The base-rate effect is the assumption that slower reaction times or eye movements in the L2 compared to the L1 simply result from slower reading rates rather than an experience-driven difference. However, Kuperman and Van Dyke (2013) demonstrated that the interaction between language proficiency and word-frequency still exists even after controlling for reaction times. Similarly, if larger frequency effects did result from reading latencies, length effects would be expected to follow the same pattern. In the current study however, length effects were larger in the L1 compared to the L2.

Thus, the difference in frequency effects may not only be a result of reading fluency, but strategies being used to access a given word. These strategies may be affected by proficiency and the degree in which bilinguals are able to adjust their reading strategies. Thus, perhaps this indicates that the difference in frequency effects between the L1 and the L2 for the current sample of Spanish-English bilingual readers in fact resulted from an adjustment of their reading strategies rather than less language exposure in the L2 compared to the L1. These findings are also consistent with the time-course of frequency effects found for participants reading in English where frequency is processed in the early eye movement measures and only low-frequency words affect the latencies of late eye movement measures. This interpretation was further quantified by the comparisons between Spanish-English bilinguals reading in English and the monolingual English readers. This comparison extends the research of Whitford and Titone (2012; 2015; 2017) by offering this comparison. These findings will be discussed further in the next section.

Based on this account, perhaps larger frequency effects between the L1 and the L2 are consistently larger given that English is usually the L2 and is regarded as the most inconsistent language. This interpretation is also consistent with the findings from *Experiment 6* (Chapter-4) where frequency effects were found to be smaller for the Spanish-English bilinguals reading in Spanish, compared to English monolinguals reading in English. This line of enquiry requires further investigation with bilinguals who’s L1 is English, and an L2 that is a more consistent orthography than English.

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Taken together, it appears as though the current sample of Spanish-English bilingual readers were able to adjust their reading strategies between their native Spanish language and their second language, English. These findings are consistent with previous research with both reaction times (Ziegler et al., 2001), and eye movement studies (Egan et al., 2019) that have demonstrated similar findings. The differences in length and frequency effects in English versus Spanish for the current sample of bilingual readers imply that when reading in Spanish, participants relied to a greater extent on the sub-lexical decoding procedure, but while reading in English, relied less on the sub-lexical procedure and more on the lexical procedure (e.g., Ellis & Hooper, 2001; Goswami, Gombert, & Fraca de Barrera, 1998; Landerl, Wimmer & Frith, 1997; Rau, Moll, Snowling & Landerl, 2015; Rau, Moll, Snowling & Landerl, 2015. Thus, these findings are also consistent with the ODH (Katz & Frost), and also the DRC model (Coltheart, Rastle, Perry, Langdon & Ziegler, 2001).

Now that it is clear that reading strategies can be adjusted by Spanish-English bilinguals, the current thesis will discuss whether these strategies can be adjusted to a degree where they begin to look like native-reading strategies. Findings from comparisons with native English readers and Spanish-English bilingual readers reading in English will be discussed in the next section.

5.3.4.3 Comparisons between Spanish-English Bilinguals Reading in the L1 vs their L2.

Although overall patterns of length and frequency effects suggest a similar pattern between Spanish-English bilinguals reading in English, and native-English monolingual readers, the current study aimed to quantify this difference using direct comparisons.

The results of these analyses indicated that bilinguals had significantly faster first fixation durations but longer gaze durations compared to English readers without dyslexia, but these were comparable to readers with dyslexia. Bilinguals had longer go-past times than English readers with and without dyslexia. Finally total reading times did not differ significantly between the groups. The size of both the length and frequency effects were not significantly different for any of the eye movement measures between any of these three groups.

These findings are particularly interesting given the nature of first fixation durations for the current sample of bilingual readers. For one, first fixation durations did not significantly differ in terms of length and frequency effects in Spanish L1 reading compared to English L2 reading for the bilinguals. Thus, it seems that strategies that drive this eye movement measure may transfer from Spanish to support English reading. This is further supported by the finding that Spanish language comprehension made significant direct contributions to English reading comprehension and Spanish language comprehension significantly correlated with this first fixation durations in *Experiment* 6 (Chapter-4). Thus, it appears as though Spanish language comprehension continues to support both Spanish reading and English reading and is reflected by first fixation durations. Evidently, Spanish-English bilinguals may compensate for the transfer of this strategy by deploying significantly longer gaze durations and go-past times, but these strategies seemed to cancel each other out since total reading times did not significantly differ between bilinguals and monolingual English readers. Since there was no difference in total reading times or the size of length and frequency effects, although the strategies of Spanish-English bilinguals were somewhat different from those of English monolinguals, they achieved the same outcome. This aligns with previous research that has reported similar results (e.g., Egan et al., 2019) that bilinguals are able to adjust their reading strategies, but also with research that suggests bilinguals transfer their reading abilities from the L1 to support reading in the L2 (Koda, 2007; Verhoeven, 1990; Pritchard & O'Hara, 2008; Royer & Carlo, 1991; Riccio et al., 2001; Lemhöfer et al., 2008; Relyea & Amendum, 2020; Deacon, Chen, Luo, & Ramirez, 2013).

Thus, although these Spanish-English bilinguals developed reading strategies largely in a consistent language, they were able to adjust their reading strategies to meet the unique demands of the English orthography, to the point where their eye movements begin to look like those of a native monolingual reader. These findings accord with those reported by

Egan et al. (2019) who found that Welsh-English bilinguals did not significantly differ from English monolingual readers in their eye movements. However, the current Experiment extends this research by also reporting this effect in total reading times and further quantifying strategies by reporting length and frequency data.

5.3.4.4 Correlations between Eye Movements measures and the Simple View of Reading Component Skills

The final goal of the current study was to investigate whether eye movement strategies might be related to the component skills i.e., decoding, language comprehension, and reading comprehension, described in the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1991). Given that decoding processes are associated with fixation and saccade measures (e.g.,Pagán, Blythe & Liversedge, 2021) as well as early eye movement measures (first fixation duration and gaze durations), it was expected that decoding skills measured in *Experiment 7* should correlate with these eye movements. Additionally, late eye movement measures (go-past times and total reading times) are associated with higher order reading skills such as semantic integration and conflict resolution (e.g., Ashby and Clifton 2005; Ashby et al., 2012; Chace et al., 2005; Häikiö et al., 2009; Haenggi & Perfetti, 1994; Jared et al., 1999; Luke et al., 2015; Veldre & Andrews, 2014). Thus, it was also predicted that these eye movement measures should be related to language comprehension and reading comprehension scores as these tasks measure similar skills.

Sentence-Level Measures

None of the global eye movement measures (i.e., average fixation duration, total fixation count, backward saccade count, and total reading time) significantly correlated with any of the offline skills measured in *Experiment 7* of the current Chapter. This is surprising given that decoding processes are associated with fixation and saccade measures (e.g., Pagán, Blythe & Liversedge, 2021) and total reading times have been found to be related to reading comprehension (e.g., Ashby and Clifton 2005; Ashby et al., 2012; Chace et al., 2005; Häikiö et al., 2009; Haenggi & Perfetti, 1994; Jared et al., 1999; Luke et al., 2015; Veldre & Andrews, 2014).

These trends were also reported in *Experiment 2* (Chapter-2) with the native English monolingual readers. However, decoding skills and reading comprehension skills in Spanish did not correlate with these eye movement measures while these same Spanish-English bilinguals read in Spanish either. Further, none of the Spanish reading abilities measured in *Experiment 5* (Chapter-4) significantly correlated with any of these eye movements employed by the bilinguals while reading in English. Some studies investigating adult bilinguals' L1 and L2 reading have reported similar results, where there appeared to be no causal relationship between reading speed and comprehension (e.g., Kang, 2014). Thus, perhaps these global eye movements employed by the current sample of Spanish-English bilinguals reflect some other skill that was not measured in the current thesis.

Further research is needed to determine whether these global measures of reading might be related to other reading skills for Spanish-English bilinguals.

Word-Level Measures

Results from with word-level measures in the current study indicated several correlations with the SVR component abilities for late eye movement measures of reading. Specifically, total reading times for low-frequency short words significantly correlated with decoding and total reading times. These correlations indicated that as these scores increased, eye movement measures for high-frequency short words decreased in milliseconds.

These findings are novel and contribute to the current literature by demonstrating that English reading abilities may drive late eye movement measures for bilinguals reading in their L2. These findings may also support the notion that SVR may better characterise bilingual reading rather than monolingual reading. These interpretations are further supported by the findings in *Experiment 7* that the SVR additive formula accounted for 68% of variance in English reading comprehension for this Sample of bilingual readers, while the same model only accounted for 45% for native-English monolingual readers, and 34% for the same readers in Spanish. Although it could be argued that the large number of correlations across eye movements and the SVR component skills, and more variance in reading comprehension is accounted for because these readers are less proficient and therefore demonstrate more variance in reading, results from the English dyslexia sample indicated that the SVR formula only accounted for 59% of the variance in reading comprehension. However, more research is needed with bilingual adults of varying proficiencies to confirm these interpretations.

5.3.4.5 Limitations and Further Research

A major strength of this experiment is that it compared both online and offline measures of reading. These comparisons offer a more in-depth view of online reading strategies as measured by eye movement patterns and how they interact with offline measured reading abilities. Further, the current chapter compared eye movement strategies from three different groups - native monolingual English speakers reading in English, and Spanish-English bilinguals reading in both Spanish and English.

Since many of the eye movement measures did not significantly correlate with the measured reading skills in *Experiment 7*, it may have been useful to measure a wider range of skills that have been found to influence reading. For example, non-word decoding, phoneme deletion tasks, rapid automatized naming, and morphological awareness are skills that have been reported to be related to reading comprehension (e.g., Goodwin, August & Calderon, 2015). Alternatively, it may also have been more informative to measure the same eye movements using a variety of different texts such as newspaper articles or scientific texts which may have elicited different eye movement strategies. Further research may benefit from testing a variety of reading abilities paired with a variety of text stimuli in eye-tracking experiments.

While fixations and saccades are informative measures of eye movements, it may also have been even more prudent to calculate distances between fixations and saccade amplitudes to further distinguish small grain decoding strategies from large grain reading strategies between the groups in the current thesis.

Future directions for this research would be to analyse Spanish-English bilinguals reading in their L1 and compare them to monolingual native Spanish readers to determine how bilingual reading differs from monolingual reading in consistent orthographies. Further, research with Spanish readers diagnosed with dyslexia may further our understanding of the consequences of orthographic consistency.

5.3.4.6 Conclusion

The present experiment aimed to explore reading strategies as measured by eye movements in bilingual Spanish-English readers while they read whole sentences for meaning in their L2 (English). The current study also compared eye movement measures of reading with the measured reading abilities of the components described in the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990). Findings from this study were also compared to those reported in Chapter-2 and Chapter-3 with native English monolingual readers with and without dyslexia and Chapter-4 with the same sample of Spanish-English bilinguals reading in their L1 (Spanish).

In the current sample the Spanish-English bilinguals reading in their L2, both early and late eye movement measures were found to be sensitive frequency effects. Word length appears to have affected only the late eye movement measures, however significant interactions between length and frequency indicated that in the case of go-past times, there were no frequency effects for short words, and no length effects for high-frequency words. Similar patterns were also found for native-English readers, but not for the same bilingual readers as they read in Spanish.

Compared to reading in Spanish, the current sample of bilinguals exhibited more frequent and longer fixations, more frequent regressions, and longer total reading times when reading sentences in English. Bilinguals also had faster first fixation durations, gaze durations, go-past times, and total reading times while reading in Spanish compared to English. Frequency effects were found to be smaller, but length effects were larger in Spanish L1 reading compared to English L2 reading, and this was evident in both early and late eye movement measures of lexical access. These findings suggested that bilinguals were able to adjust their strategies to meet the demands of English, and further comparisons with native English monolingual readers indicated that these strategies were adjusted to the point where they looked native-like. Further, although these readers developed their reading skills largely in Spanish, where phonology is consistent, these readers performed better than the native-English dyslexic readers thus suggesting that although orthography may perpetuate instances of dyslexia, it is likely not a predominate causal factor.

Some degree of cross-linguistic transfer was detected, particularly in first fixation durations which were shorter for the bilingual readers than for Spanish-English bilinguals reading in English exhibited comparable fixation durations, fixation counts, regression counts and total reading times as English native readers without dyslexia. However, bilingual readers had significantly fewer fixations and regressions and faster total reading times than English dyslexic readers. Bilinguals also had significantly faster first fixation durations but longer gaze durations compared to English readers without dyslexia, but comparable to readers with dyslexia. Bilinguals had longer go-past times than English readers with and without dyslexia, while total reading times did not differ significantly between the groups. The size of the length and frequency effects were not significantly different for any of the eye movement measures.

Finally, there were no significant correlations between the SVR component skills and the sentence-level measures, however all the SVR components, but not vocabulary did significantly correlate with both early and late measures of word-level reading.

Taken together, these findings provide support for the notion that bilingual readers of two orthographies that differ in consistency are largely able to adapt their reading strategies between their L1 and L2 to meet the unique demands of each orthography. Specifically, when reading in Spanish, these bilinguals demonstrated a pattern of predominate reliance on sub-lexical decoding and a small-grain processing strategy, however while reading in English, bilinguals were able to adapt a strategy that largely reflected a lexical process of reading using larger-grains of information. These strategies significantly differed between the L1 and the L2, but findings suggested that they appeared to be native-like compared to monolingual English readers and this was apparent in both early and late stages of reading as indexed by eye movement measures. These findings support both the weak version of the ODH (Katz & Frost, 1992) and the Psycholinguistic Grain Size Theory (Ziegler & Goswami, 2005).

Chapter 6: General Discussion

6.1 Chapter 6 Overview

The current Chapter summarises the research findings across the eight experiments that comprise the current doctoral thesis. Key findings are highlighted with a subsequent discussion that harmonises findings from each experiment and their novel contributions to current theoretical frameworks and reading models will be offered with a consideration of, not only scientific, but real world contributions. Following this, the current Chapter will offer a consideration of the limitations of the experiments and will discuss future avenues for this research.

6.2 Summary of Findings and Theoretical Implications

The overall goal of the current thesis was to characterise reading patterns across readers of alphabetic orthographies differing in consistency using both cognitive measures of reading and eye-tracking methodologies, guided by cognitive and psycholinguistic theoretical frameworks and models of reading. Specifically, the role of orthographic consistency in conjunction with phonological decoding in reading development, word reading processes, and the prevalence of DD were investigated. Chapter-1 offered an introduction to reading processes and considered theoretical frameworks such as the DRC (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) and connectionist triangle models (Plaut, 1999; Plaut et al., 1996; Seidenberg & McClelland; 1989) establishing an argument that word reading processes differ as a function of orthographic consistency. Specifically, the processes of phonological decoding in word identification differ across orthographies and thus, models of reading that have been developed in English, may not be appropriate for all orthographies. Following this, a discussion of how these word reading processes develop between orthographies was offered and was contextualised within a prominent model of reading development, namely the SVR Model (Gough & Tunmer, 1986) with an argument that phonological dyslexia may in part be perpetuated by orthographic consistency (e.g., Wydell & Butterworth, 1999).

To address the arguments proposed in Chapter-1, experimental Chapters 2-5 investigated reading patterns from native-English readers with and without dyslexia, and in bilingual Spanish-English readers reading in both Spanish and English. Each experimental Chapter consisted of two experiments; (1) a behavioural experiment guided by the SVR framework which measured and analysed developed reading abilities and (2) a subsequent eye-tracking experiment which investigated word identification processes through objective methods. The findings from these experiments offer a novel account of developed reading abilities and differences in reading strategies across orthographies that differ in grapheme-phoneme-correspondence (GPC) consistency.

6.3.1 The Simple View of Reading and the Nature of Decoding Across Orthographies

In *Experiments 1, 3, 5, and* 7 the role that decoding, language comprehension, and vocabulary play in reading comprehension across orthographies was investigated. These experiments examined how such reading abilities had been developed by adult readers of English with and without dyslexia and Spanish-English bilinguals in both their L1 (Spanish) and L2 (English), which differ in terms of their orthographic consistency. Each Chapter measured decoding, language comprehension, reading comprehension and vocabulary in these groups, and tested the predictions of SVR model (Gough & Tunmer, 1986).

In *Experiment* 1 (Chapter-2) the predictions from the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990) were tested in skilled monolingual English readers without dyslexia. Findings supported some, but not all the predictions of the SVR. Specifically, the component variables (i.e., decoding and language comprehension) were correlated with each other and good predictors of reading comprehension on their own, with language comprehension emerging as a better predictor than decoding. The multiplicative relationship between the component variables (Decoding (D) x Language Comprehension (LC)) predicted just under half the variance in reading comprehension (RC), although the SVR claims to account for all variance in reading comprehension. However, some results were inconsistent with the predictions of the SVR. Specifically, it remains unclear whether the product model (RC = D x LC) or the additive model (RC = D + LC) can best account for the variance in reading comprehension in a given sample. Second, the two main components described in the SVR (decoding and language comprehension) do not always account for (1) the same proportion of variance across different studies within samples of the same skill level; and (2) the variance in reading comprehension. This observation led to investigations into third component variables such as vocabulary knowledge, that may explain additional variance in reading (e.g., Adolf, Catts, & Little, 2006; Braze, Tabor, Shankweiler, & Mencl. 2007; Cartwright, 2002; Johnson, Jenkins, & Jewell, 2005; Joshi & Aaron, 2000; Tiu et al., 2003). In *Experiment 1* (Chapter-2) vocabulary knowledge contributed unique variance to reading comprehension above and beyond decoding and language comprehension. These findings contributed to understanding of the reading process and suggest that although the SVR may be a good foundation in accounting for variance in reading comprehension, it does not provide the whole picture for all readers.

Hence, the findings from *Experiment 1* highlighted key limitations of the SVR. This is concerning since the Rose (2009) definition of dyslexia, which is widely coordinated within the United Kingdom, is built upon the assertions of the SVR. Specifically, Rose (2009) considers evidence in support of the SVR to argue that there are two main interactive dimensions in reading; language comprehension and word recognition. Rose (2009) agrees with the position of the SVR (Gough & Tunmer 1986; Hoover & Gough, 1990) that readers can be placed into one of four quadrants along the SVR continuum. Each of these dimensions is based on a combination of language comprehension and word recognition skills. indicating specific areas of literacy difficulty. However, the role that vocabulary played for readers without dyslexia in *Experiment 1* (Chapter-2) suggests that perhaps this way of characterising reading difficulties is incomplete and at least vocabulary should be considered as a third interactive factor.

These findings thus led to the investigation of the SVR and vocabulary in *Experiment* 3 (Chapter-3) where the predictions from the SVR (Gough & Tunmer, 1986; Hoover & Gough, 1990) were tested in native-English adults with dyslexia. Although language comprehension, vocabulary and reading comprehension scores did not significantly differ from readers without dyslexia, decoding scores were significantly poorer suggesting a primary difficulty in phonological decoding. These findings support the Phonological Deficit Hypothesis (Bradley and Bryant, 1978; Brady and Shankweiler, 1991; Ramus & Ahissar, 2012; Snowling, 1981; Vellutino, 1979) and suggest that phonological deficits do indeed play a significant role in the observed reading behavioural outcomes in readers with dyslexia (e.g., Hulme et al., 2012; Melby-Lervåg, Lyster & Hulme, 2012; Share & Stanovich, 1995; Snowling, 1995; Snowling et al., 1997; Vellutino et al., 2004). These findings also provide support for intervention models based on developing phonological processes over oral language skills (e.g., Bowyer-Crane et al., 2007). Contrary to the predictions of the SVR, decoding did not significantly predict reading comprehension however, language comprehension and vocabulary were good predictors of reading comprehension. These findings reflect the poor decoding skills of dyslexic readers compared to their adequate command of language comprehension and vocabulary to support reading comprehension. These findings do not necessarily invalidate the notion that readers may be placed somewhere on a continuum on the dimensions of both language comprehension and decoding, they suggest that a third dimension which incorporates vocabulary may be useful in interpreting the extent of literacy problems in readers of English.

Importantly these findings further our understanding of the persistence of dyslexia in adult readers, particularly the adults in continued education. Although poor decoding skills were observed in readers with dyslexia, results suggested that these readers were able to perform as well as their peers on the measures of language comprehension, reading comprehension and vocabulary. According to the SVR, if either decoding or language comprehension is impaired, reading comprehension will also be impaired. Contrary to these predictions however, there was no significant difference between these readers with and without dyslexia on the measure of reading comprehension. An alternative explanation is that reading comprehension is better explained by an additive contribution of the SVR components where language comprehension is not dependent on the level of decoding but makes an additive contribution on top of decoding to reading comprehension (e.g., Dreyer & Katz, 1992; Chen & Vellutino, 1997; Kershaw & Schatschneider, 2012; Neuhaus et al., 2006; Savage, 2006; Savage & Wolforth, 2007; Tiu, Thompson & Lewis, 2003). Indeed, this additive relationship was adequate in accounting for variance in reading comprehension in readers with and without dyslexia in the current thesis, thus indicating that although phonological deficits may persist into adulthood, readers with dyslexia may be able to compensate for poor phonological skills through vocabulary and language comprehension to support adequate reading comprehension. Therefore, it is important that these skills are also emphasized during literacy instruction for readers of English.

In terms of the developmental timeline of these two component skills, previous research has demonstrated that decoding becomes less important as readers age when language comprehension begins to better predict reading comprehension (e.g., Catts et al., 2003; Catts, Adlof, & Weismer, 2006; Garcia & Cain, 2014; Hoover & Gough, 1990; Oakhill, Cain, & Bryant, 2003; Tilstra et al., 2009). These reports suggest that after an adequate level of decoding has been achieved, language comprehension is able to further develop to support reading in English. As evidenced by results from *Experiment 1* (Chapter-2) and *Experiment 3* (Chapter-3) at the end of development in adulthood, indeed reading comprehension is best reflected by the level of language comprehension more than decoding. The implications of these findings suggest that perhaps intervention programs for readers with dyslexia should provide initial support and intervention with phonology only until an adequate level of decoding is reached and following that, intervention should prioritize the development of language comprehension and vocabulary.

The next goal of this doctoral research was to contextualize the above findings within the role of orthographic depth. As discussed in Chapter-1, orthographic depth differs across languages in terms of the consistency of GPCs and may influence development of reading skills, particularly phonological decoding (Frost & Katz, 1987; Frost, Katz, & Bentin, 1987; Katz & Frost, 1992). Phonological decoding skills are necessary for word reading in all alphabetic languages, but the process behing phonological decoding is easier in languages such as Spanish with consistent GPCs compared to languages like English with inconsistent GPCs (e.g., Aro & Wimmer, 2006; Frost & Katz, 1987; Frost, Katz, & Bentin, 1987; Seymour, Aro, & Erskine, 2003). As a result, readers of consistent languages can rely on sub-lexical decoding strategies while readers of inconsistent languages develop decoding at a much slower rate and must develop lexical strategies to overcome the unpredictable nature of inconsistent GPCs (e.g., Ellis & Hooper, 2001; Goswami, 2010; Perfetti & Harris, 2017; Seymore Aro, & Erskine, 2003). The next set of experiments aimed to examine the outcomes of the developmental differences and investigate whether SVR could apply to native readers of a consistent orthography. To this end, the SVR predictions were tested in a group of Spanish-English bilingual readers whose Spanish reading abilities were measured in *Experiment 5* (Chapter-4).

In *Experiment* 5, Spanish decoding scores were near ceiling level for the Spanish-English bilinguals indicating a high competency with Spanish decoding. Thus, these skills may reach ceiling levels of efficiency for skilled readers of Spanish due to the high consistency between graphemes and phonemes and thus decoding is no longer a good predictor of variance in reading comprehension. These findings are in contrast to the native English readers whose decoding skills were not as efficient. Taken together, these findings support the ODH (Katz & Frost, 1992) and agree with previous research reporting that decoding is more reliable in consistent orthographies compared to inconsistent ones (e.g., Aro & Wimmer, 2006; Frost & Katz, 1987; Frost, Katz, & Bentin, 1987; Seymour, Aro, & Erskine, 2003). These findings highlight the strength of decoding skills developed in a consistent language and the importance of continued development of decoding skills for readers of inconsistent languages to support reading.

Variance in Spanish reading comprehension was only predicted by Spanish language comprehension for the sample of adult Spanish-English bilingual readers. However, language comprehension only predicted a small amount of variance in Spanish reading comprehension. Similarly, the SVR accounted for only 33% of the variance in reading comprehension and in contrast to readers of English without dyslexia, vocabulary knowledge did not contribute to variance in reading comprehension in this sample of Spanish-English bilinguals. Presumably this is because these skills are able to develop sooner for readers of consistent languages because decoding is also developed at a faster rate than it is in incognisant orthographies (e.g., Florit & Cain, 2011; Goswami, 2002; Joshi et al., 2012; Seymour, Aro, & Erskine, 2003). Taken together, these findings imply that variance in Spanish reading for adults may be better characterised by some other skill not measured in the current doctoral thesis. For example, reading speed has been found to be a good predictor of reading (e.g., Defior et al., 2011). Again, both the multiplicative model and the additive model of the SVR were adequate at a similar level in accounting for variance in reading comprehension. These findings disagree with the assertions of the SVR and again imply that language comprehension and decoding are sufficient, but not necessary for reading comprehension at least for adult readers of Spanish. Overall, it appears as though adult readers of Spanish, a consistent orthography may be at a developmental advantage to their native English peers in reading even in adulthood.

Finally, the next theoretical question the current doctoral thesis aimed to address was how readers with a consistent orthography for their native language would approach a second language differing in orthographic consistency. Chapter-5 employed the SVR theoretical framework to investigate second language (English) reading patterns of the same Spanish-English bilinguals from *Experiment 5* (Chapter-4).

Experiment 7 (Chapter-5) indicated that the same Spanish-English bilingual readers used both Spanish and English reading abilities to support reading in English. English decoding, language comprehension and vocabulary were all significant independent predictors of reading comprehension, however, language comprehension was the best predictor. These results indicate that the sample of Spanish-English bilinguals developed reading strategies that closely resembled native-English speaking peers without dyslexia. These findings are critical given the influence the SVR has on diagnostic criteria for dyslexia.

As previously proposed, one potential use of the SVR could be to help identify second language reading disabilities. A particularly important consideration is whether the SVR could detect reading disabilities versus general language fluency difficulties in bilingual readers. Bilingual children reading in English as a second language may be assumed to be performing poorly in their L2 when, in fact, they may be struggling with a reading disability. This may be particularly true when the L2 is an inconsistent language such as English. For example, learners of a second language might perform well in L2 speaking and listening tasks, but poorly in L2 reading tasks. However, if L1 reading skills are not considered in the current model of the SVR there is a gap in understanding the specific nature of L2 reading comprehension. For example, in the sample of Spanish-English bilinguals, their Spanish decoding made significant indirect contributions via English language comprehension and made significant total contributions despite a nonsignificant indirect contribution through English decoding. This indirect relationship may suggest that the relationship between Spanish decoding and English reading comprehension is fully mediated by English language comprehension skills. Further, Spanish language comprehension made direct contributions to English reading comprehension suggesting that if Spanish language comprehension was poor, English reading comprehension may suffer as a result. This finding may be particularly important for younger native readers of Spanish, or any consistent orthography who are learning to read in English. As previously discussed, decoding may be sufficient, especially for younger readers of a consistent language and thus language comprehension is not a good predictor of reading comprehension at early ages (Goswami, 2002; Seymour, Aro, & Erskine, 2003, Hoover & Gough, 1990). If a developing reader of a consistent language subsequently must learn English as an L2, they may not have sufficient skill in L1 language comprehension to support L2 reading comprehension. Further research with younger readers of a consistent orthography who are learning English as an L2 is needed to validate these interpretations.

Overall, these findings lend support to the ODH (Katz & Frost, 1992) and indicate that strategies differ across orthographies particularly in relation to decoding skills. Specifically, these findings support the weak version of the ODH (Katz & Frost, 1992) which purports that both the lexical and sub-lexical procedures (or routes) suggested by the DRC model (e.g., Coltheart et al., 2001) are available to all readers, but their uses are dependent on the demands of the orthography being read. Continued success with the sub-lexical procedure and the ease of GPC decoding in the consistent Spanish language appears to have yielded a mastery of Spanish decoding for the Spanish-English bilinguals. Thus, variance in decoding is null and no longer predicts variance in reading comprehension. However, it appears that Spanish-English bilinguals reading may also use vocabulary and language comprehension to support reading in Spanish. Similarly, native-English readers use these skills to support reading in English, however, they have not mastered English decoding to the same degree of the Spanish-English bilinguals indicating their prolonged success with the lexical over the sub-lexical route to support English reading. However, when approaching an inconsistent orthography, these same Spanish-English bilinguals were able to develop reading abilities that more closely resembled those of native-English readers.

Reading Behaviour Between a Consistent and an Inconsistent Orthography

Although the findings form this thesis may support aspects of the ODH, it is important to note that the ODH can only apply to alphabetic orthographies. However, it is necessary to consider current research which has shifted focus to bicipital readers and bilingual readers of non-alphabetic languages. There may be differences in reading processes between bilingual-monoscriptal readers (Spanish-English) and bilingual readers of alphabetic and non-alphabetic languages (e.g., Chinese-English).

The above describes how developed reading skills in both native-English and Spanish-English bilinguals manifest in reading comprehension and the role of orthographic depth. Findings from the behavioural study were further validated by investigating reading patterns in each of these groups through objective eye-tracking methodologies. The next section will discuss how these developed reading skills may drive specific reading strategies as indicated by eye movement patterns.

The overall conclusions from *Experiments 1, 3, 5, and* 7 suggested that the SVR framework may be a good starting point in accounting for variance in reading comprehension, but it was not supported as a model that accounted for all variance in reading comprehension in all types of readers. The SVR framework may not be useful in characterising reading comprehension in Spanish, particularly for experienced readers. Likely, this is because of the nature of decoding in each language. Decoding is rapidly acquired in Spanish, which is a consistent orthography and predicts early reading acquisition (e.g., Goswami, 2002; Seymour, Aro, & Erskine, 2003; Hoover & Gough, 1990), however once children master decoding around age 7 in Grade-1 or Grade-2 (Defior et al., 2011), language comprehension begins to predict variance in reading comprehension (Florit & Cain, 2011; Joshi et al., 2012). For English readers however decoding is indistinguishable from language comprehension until around Grade-3 (age 9) (Lonigan & Burgess, 2017) and decoding is better than language comprehension at predicting variance in reading comprehension until readers of English are older (Florit & Cain, 2011; Joshi et al., 2012). For example, Joshi et al. (2012)

reported that language comprehension exerted a greater influence to reading comprehension than decoding for Spanish-speaking children in Grade-2 and decoding was no longer a significant predictor by Grade-3, while the opposite pattern was found for the English sample in Grade-2, but by Grade-3 decoding and language comprehension exerted equal influence to reading comprehension. For these reasons, the relationship between decoding and language comprehension may not predict reading comprehension for readers of Spanish. However, it is possible that the relative contributions of decoding and language comprehension may differ at earlier development points for readers of Spanish, especially in the early years when decoding is still developing. Further research is needed to confirm this possibility. However, findings from the current experiments suggest that adult readers of a consistent language may still be benefiting from a developmental advantage by reading in a consistent orthography.

Although the product of decoding and language comprehension explained at least some variance in reading comprehension for each group thus providing some support for the SVR as an overall framework to explain variation in reading comprehension, findings from the experiments across these groups also challenged several of the SVR hypotheses. The SVR maintains that reading comprehension is the product of decoding and language comprehension and makes three key testable predictions. The first prediction states that the relative contributions of decoding and language comprehension to reading comprehension is best characterized by a product model (Reading Comprehension (RC) = Decoding (D) x Language Comprehension (LC)), rather than an additive equation (RC = D + LC). Further, the second prediction argues that since the relationship between decoding and language comprehension is multiplicative to explain variance in reading comprehension, it follows that for increasing levels of decoding skill, there should be a constant intercept value of 0 in a regression formula and positive slope values increasing in magnitude. Overall, the experiments reported in this thesis do not support these two predictions. Findings from both native-English readers with and without dyslexia and Spanish-English bilinguals in both

Spanish and English suggested that an additive model of the SVR components could account for variation in reading comprehension as well as the product model. The implications of these findings are twofold. First, decoding and language comprehension are indeed sufficient, but *not* necessary for reading comprehension. In other words, the additive model implies that there could be skill in reading comprehension even in complete absence of either decoding or language comprehension. This implies that other skills may contribute to reading comprehension. Indeed, in *Experiment 1* (Chapter-2), vocabulary contributed to unique variance in reading comprehension in addition to decoding and language comprehension. Second, since vocabulary knowledge did not account for unique variance for any other group suggesting that perhaps some skills that were not measured may also contribute to reading comprehension for these groups. For example, other reading abilities such as attentional control (Connors, 2009), letter naming speed (Joshi & Aaron, 2000), or reading speed (Cutting & Scarborough, 2006) have been found to account for additional proportions of variance in reading comprehension (Binder et al., 2017; Braze et al., 2007; Vellutino et al., 2007; Ouellette & Beers 2010; Tunmer & Chapman, 2012).

The third prediction of the SVR postulates that the rate of improvement in reading comprehension due to improvement in language comprehension is contingent upon an increase in decoding skill with slopes increasing in magnitude from a floor of zero. For example, for a reader with perfect decoding skills (D = 1) further improvement in reading comprehension would be identical to the improvement in language comprehension. This prediction was not supported by the data from the current thesis. A clear example comes from *Experiment 5* (Chapter-4) where Spanish decoding skills were near perfect for the Spanish-English bilinguals. Although the additive and multiplicative models did not account for additional variance in reading comprehension above the contribution of language comprehension, these models only accounted for a small (33%) amount of variance in reading. This finding suggested that decoding and language comprehension may not sufficiently characterise variance in reading comprehension and suggest that other reading skills such as vocabulary knowledge, or other reading or visual skills not measured in the current thesis may contribute to reading comprehension. The SVR was developed and tested in readers of English orthography, which yields a different developmental pattern to Spanish and bilingual readers. Hence, the SVR which was developed to account for English reading comprehension may be language specific and therefore cannot accurately account for Spanish reading comprehension. These findings further support the developmental difference in reading comprehension between consistent and inconsistent orthographies.

The findings from *Experiments 1, 3, 5, and* 7 provide a novel account of the SVR in native-English adult readers with and without dyslexia and Spanish-English bilingual adult readers in both Spanish and English. These findings present challenges to the SVR as an approach to predict reading comprehension. This is particularly critical given that this model supports current definitions of DD (Rose, 2009) used for diagnostic and intervention approaches within the United Kingdom. For the dyslexic readers from *Experiment 3* (Chapter-3), although decoding scores were significantly poorer than the English readers without dyslexia, reading comprehension was not. In dyslexic readers. decoding did not significantly predict reading comprehension, however language comprehension was a strong predictor. These findings reiterate the suggestion that decoding may be sufficient, but *not* necessary for reading comprehension and thus may be bypassed at least partially, especially in inconsistent languages such as English (e.g., Chen & Vellutino, 1997; Savage, 2006; Savage & Wolforth, 2007).

6.2.2 Reading Strategies Across Orthographies and Consequences for Dyslexia

Eye movements were measured in native-English readers with and without dyslexia and in Spanish-English bilinguals as they read in both Spanish and English in *Experiments 2, 4, 6 and 8.* The purpose of these experiments was to explore the reading strategies that develop as a function of orthographic consistency. Each chapter reviewed current literature that has investigated reading strategies in each of these groups and evaluated the extent to which current theoretical frameworks can account for findings across the literature.

Although reading processes have been investigated extensively in native-English readers, *Experiment 2* (Chapter-2) extended previous findings by investigating both text level influences (i.e., length and frequency) and individual differences (i.e., decoding, language comprehension, reading comprehension, and vocabulary) for both early (first fixation duration and gaze duration) and late (go-past times and total reading times) eye movement measures. Prior to this, previous research had not investigated each of these items in conjunction. Further, the findings from the native-English readers without dyslexia were subsequently compared to those of readers with dyslexia (Chapter-3), Spanish-English bilinguals reading in Spanish (Chapter-4) and Spanish-English bilinguals reading in English (Chapter-5). These novel investigations aimed to provide a direct comparison of how reading strategies differ across these groups of readers to illustrate the role of orthographic consistency in reading strategies.

According to the DRC model (Coltheart et al., 2001), word identification is achieved along one of two routes (1) a sub-lexical decoding route or (2) a lexical route where whole words are retrieved via the lexicon. It is assumed that word-frequency and length effects reflect the use of lexical and sub-lexical reading strategies, respectively. Evidence of both reading strategies were observed across each group in the current thesis suggesting some level of language universal processes, however the extent of the use of these strategies and the time-course of these strategies differed for each group suggesting that some processes may be language specific.

In *Experiment 2* (Chapter-2), reading patterns were investigated via eye movement measures in the same sample of skilled monolingual English readers without dyslexia whilst they read sentences for meaning. As predicted by the DRC model of reading (e.g., Coltheart et al., 2001) and the ODH (Katz & Frost, 1992), successful reading processes for skilled readers of English demonstrated a use of both the lexical and sub-lexical procedure. Native-English readers without dyslexia were sensitive to word-frequency in early (first fixation duration and gaze duration) and late (go-past times and total reading times) eye movement measures of reading, while length effects were found for late eye movement measures of reading. Thus, frequency effects indicate that this sample of monolingual English readers largely relied on lexical processes to support reading at both early and late-stages of lexical access while word length affected late-stage lexical access. These findings are consistent with previous research reporting that frequency may affect early lexical access (e.g., Ashby Rayner & Clifton, 2005), however, the novelty of these findings also demonstrate that frequency may affect all stages of reading while length may only affect later stages of lexical access for native English readers.

Findings from *Experiment 2* (Chapter-2) also indicated that component skills from the SVR and vocabulary knowledge correlated with both sentence-level and word-level eye movement measures, albeit early eye movements were best at predicting decoding and reading comprehension in the current cohort of skilled readers of English. These results, and specifically decoding, reflect the reliance on early lexical access such as phonological processing (Rayner, 1998; Rayner, Chace, Slattery, & Ashby, 2006). Thus, better decoding skills may lead to faster and more efficient lexical processing particularly when reading low-frequency words. These findings emphasise the role of decoding and phonological skills for faster word recognition and the importance of developing these skills for reading in English.

Such findings raised questions about how these same processes may operate in developmental dyslexic readers of English who may struggle with phonological processing. If DD results from a phonological deficit versus a visual deficit, it was expected that the sample of dyslexic readers would be sensitive to text-level properties and demonstrate larger length and frequency effects than readers without dyslexia. However, since English readers with DD still demonstrated length effects (a visual characteristic of text), it is not possible to rule out a visual deficit entirely. Further, the current study did not compare English readers with DD and Spanish readers with DD. Furture studies would benefit from such a comparison to determine the extent to which a phonologically transparent language may mitigate phonological deficits in DDs. According to the HGT (Wydell & Butterwoth, 1991) phonological dyslexia would be rare in two conditions: (1) in transparent (consistent) orthographies (2) even in opaque (inconsistent) orthographies, if the smallest graphemic unit representing sound is equal to a whole character or a whole word (i.e., coarse grain), as opposed to a phoneme (i.e., fine grain). However, it is possible that instances of DD in consistent orthographies may stem from a visual deficit since phonological information is transparently available in a text. The high demand that inconsistent alphabetic languages such as English place on phonology affects the rate of phonological development. Compared to readers of consistent orthographies, readers of inconsistent ones develop phonological skills at a much slower rate (e.g., Seymour, Aro & Erskine, 2003). For these reasons, it was proposed that English readers with dyslexia would demonstrate a deficit in phonological processing which would also be evident in their eye movements. Chapter-3 reviewed the available eye movement research on readers with dyslexia, which suggested that eye movements for readers with dyslexia were distinct from readers without dyslexia. In particular, eye movements appear to reflect deficits with phonological processes and demonstrated poor sub-lexical reading strategies (e.g., Ellis & Miles, 1981; Goldberg & Arnot, 1970; Provazza et al., 2019; Rayner, 2009; Tanenhaus, Magnuson, Dahan, & Chambers, 2000; Ziegler et al., 2003). Subsequently, it was suggested that the current thesis research could extend these findings by offering an eye movement account of dyslexic readers using both the early and late eye movement measures which had not been investigated in adult readers with dyslexia.

Indeed, the consequences of the inconsistent English orthography were observed in native-English readers with DD in *Experiment 4* (Chapter-3). Compared to native-English readers without dyslexia, readers with dyslexia demonstrated distinct eye movement patterns with more regressions and fixations and longer reading times indicative of a poor sub-lexical decoding strategy. Dyslexic readers also demonstrated a differential time-course of word-level effects where word-frequency affected early lexical access and word-length affected later lexical access. Early eye movement measures (first fixation durations and gaze durations) were found to be affected by word-frequency while late eye movement measures (go-past times and total reading times) were influenced by word length (e.g., Ashby, Rayner & Clifton, 2005; Blythe et al., 2009; Inhoff and Rayner 1986; Rau et al., 2015). Mean eye movement measures suggested that these effects were larger for readers with dyslexia than the age-matched typically developing readers. These findings are consistent with reaction time data as has been observed in previous studies (e.g., Hyona & Olson, 1995, Provazza et al., 2019; Richlan et al., 2010; Ziegler et al., 2003; Zoccolotti et al., 2005), but contribute to this literature by providing an account of this effect in adult readers' eye movements. Interestingly, although it was not a significant effect, compared to typically developing readers, readers with dyslexia demonstrated shorter early measures of reading when reading high-frequency words which may reflect their compensatory strategies and reliance on vocabulary and language comprehension. These findings also accord with the DRC (Coltheart et al., 2001) and may lend support to phonological deficits (Bradley and Bryant, 1978; Brady and Shankweiler, 1991; Snowling, 1981; Vellutino, 1979) as a predominant cause of dyslexia rather than a visual deficit (e.g., Stein, 2001; Valdois et al., 2004) in English readers with DD.

The findings from native English readers with and without dyslexia raised questions regarding how eye movements may differ in a language with a consistent orthography. In *Experiment* 6 (Chapter-4), the eye movements of Spanish-English bilinguals were subsequently tracked as they read sentences for meaning in Spanish, their native language. The eye movements employed differed from those of the native-English readers. Thus, although Spanish-English bilinguals and English monolinguals read with comparable speed and accuracy in their respective native languages, they demonstrated different patterns of eye movement behaviour. Similar findings have come from fMRI research which show that native processing in each of these languages come with distinct brain activation patterns (e.g., Jamal et al., 2012; Kovelman, Baker & Petitto, 2008).

As previously discussed, the ODH (Katz & Frost, 1992) posits that readers of consistent orthographies can take advantage of GPCs and rely to a greater extent on sub-lexical processes to support word recognition. Readers of inconsistent orthographies, however, cannot rely on sub-lexical reading strategies and must support reading through the lexical procedure. The weak version of the ODH acknowledges that both the sub-lexical and lexical route are available to all readers but reading strategies may differ across orthographies because of their successes or failures with the lexical and sub-lexical reading strategies. In support of the weak version of the ODH, both length and frequency effects were found in early and late eye movement measures for the Spanish-English bilinguals reading in Spanish however interactions indicate that there was only an effect of frequency for long words, but not short words. Larger length effects and smaller frequency effects were found for Spanish-English bilinguals reading in Spanish, compared to readers of English for each of the eye movement measures. These effects indicated that the Spanish-English bilinguals reading in Spanish relied to a greater extent on sub-lexical strategies than the English readers without dyslexia, which accords with previous accounts (Goswami et al., 1998; Landerl et al., 1997; Rau et al., 2015). Taken together these findings suggest that a sub-lexical decoding strategy may not necessarily be the dominant reading strategy for adult readers of a consistent orthography, but there is greater reliance on this strategy compared to readers of an inconsistent orthography.

In terms of the PGST (Ziegler & Goswami, 2005) the reliance on the sub-lexical decoding strategy reflects the use of smaller grains (or units) such as phonemes when reading. The PGST posits that readers of consistent orthographies can rely heavily on smaller grains to support reading because phonemes are consistently predictable. This is particularly true for unfamiliar low-frequency words. Readers of inconsistent orthographies with irregular GPCs, however, must develop strategies that use a variety of both small and large grains such as rimes and whole words. The differences between length and frequency effects across orthographies is interpreted to reflect the use of either small grain or larger grain reading strategies. The larger length effects found for readers of consistent orthographies compared to readers of inconsistent indicate a reliance on small unit decoding strategies, whereas readers of consistent orthographies may use larger grain size strategy which is not slowed by length. For the same reason, readers of consistent orthographies may use a small unit decoding strategy to process both high-frequency and low-frequency words at the same rate, whereas the larger unit strategy employed by readers of English is slowed by word-frequency.

According to the DRC model (Coltheart et al., 2001) frequent words are more readily available in the lexicon because they are read more often and can more easily be accessed by the faster lexical route. When the lexical route fails to find a reliable match, the slower sub-lexical procedure is used to decode the word. The results from the English sample of readers without dyslexia indicate that early eye movement measures which may reflect initial lexical access particularly to the phonological properties of the word, and may rely on decoding skills (Pagán, Blythe & Liversedge, 2021; Rayner et al., 1998; 2003; Sparrow & Miellet, 2002; Slattery, Pollatsek & Rayner, 2006) were only affected by word-frequency. The interaction of length and frequency effects also suggested that the length effect was only found for low-frequency words. Given that the sub-lexical route may not always be reliable for English readers, English readers may attempt to abandon the sub-lexical procedure to make use of the lexical route which will be slowed when matches are not easily found. Thus, slowing late processes of lexical access rather than early ones. These processes however were found to be distinct for the bilingual readers of Spanish, a consistent orthography. The bilingual sample reading in Spanish were sensitive to word-frequency for both short and long words. First fixation durations were only sensitive to frequency effects and not length effects, this may suggest that a lexical procedure may be automatically applied based on early lexical information (e.g., Goswami et al., 1998, Rau et al., 2015). Since frequency effects in early eye movement measures were only found for short words, this may suggest that if the word was short, a lexical strategy may have been deployed based on early lexical information (i.e., first fixation durations and gaze durations) which minimised the need for longer processing in the late eye movement measures of lexical access which showed no frequency effect for short words. However, if words were low-frequency, word length determined whether the lexical or sub-lexical procedure was employed such that the longer the word, the more likely the sub-lexical procedure would be used. Similar results have been reported for other readers of consistent orthographies (e.g., Goswami, Gombert, & Fraca de Barrera, 1998, Rau, Moll, Snowling & Landerl, 2015).

One theoretical question raised in Chapter-1 was the extent to which readers who largely developed their first language reading skills in a consistent orthography could adapt their second language reading strategies to meet the demands of an inconsistent orthography. Chapter-5 reviewed the available eye movement studies that have demonstrated strategies bilinguals used between an L1 and an L2 of differing orthographic depth, and studies that have compared L2 reading strategies with native monolingual readers. Findings from this research suggests that fluent bilinguals can adjust their reading strategies to the point where they begin to appear native-like in their L2 even when orthographic consistency differs between the two languages. However, for less proficient bilinguals, there still may be evidence of transfer from an L1 to an L2 which may occur at certain points in the reading process (e.g., Egan et al., 2019; Libben & Titone, 2009; Titone, Libben, Mercier, Whitford, & Pivneva, 2011; Ziegler et al., 2001). Further, there were some areas of this research that require further clarity, in particular, the role of eye movement measures that represent late lexical access (i.e., go-past times and total reading times) have been understudied in previous literature. Chapter-5 addressed these contentions by comparing both early and late eye movement patterns of Spanish-English bilinguals reading in English with the patterns they employed in Spanish and with the patterns observed by native-English readers. *Experiment 8* (Chapter-5) then measured eye movements of the Spanish-English bilinguals as they read in English.

Although there was evidence of transfer of some reading abilities to support L2 reading in *Experiment 7* (Chapter-5), Spanish-English bilinguals appeared to adapt their reading strategies to meet the demands of the inconsistent English orthography. These strategies were adapted to the point where they significantly differed from their strategies they used to read in Spanish, and they appeared almost native-like. The finding that bilingual readers may be able to adjust their reading strategy has also been reported in previous studies (e.g., Egan et al., 2019; Zeigler et al., 2001). The novelty of the current research extends these findings by demonstrating the extent to which bilingual L2 reading strategies differ from L1 reading strategies.

For the Spanish-English bilinguals reading in their L2 (English), both early and late eye movement measures were found to be sensitive to frequency effects. Word length appears to have affected only the late eye movement measures. The time-course of these effects were the same for native-English readers, but not for the same bilingual readers as they read in Spanish indicating that in English, frequency affects both early and late lexical access while length affects late lexical access. This time-course suggests that the lexical route may be the default for English readers and when that fails, the sub-lexical route is deployed. That is, it appears as though the bilinguals are employing a lexical reading strategy that processes larger grains of information at a time, rather than employing a sub-lexical reading strategy to read in English. Given that these bilingual readers did not demonstrate significantly slower reading times from the English native readers, these findings indicate that these strategies are being employed sufficiently. Interestingly, the Spanish-English bilinguals demonstrated a more efficient reading strategy compared to the native-English readers with dyslexia. These results imply that despite more experience reading in a consistent orthography which requires different reading strategies, proficient bilinguals may be able adjust their reading strategies without suffering the same consequences as dyslexic readers who struggle with the phonological inconsistencies of the English language. These findings perhaps have further implications for dyslexic readers suggesting that orthography may perpetuate phonological difficulties associated with dyslexia, but they may not necessarily largely stem from orthographic inconsistency.

Although overall patterns of length and frequency effects suggest a similar pattern between Spanish-English bilinguals reading in English, and native-English monolingual readers, the current study aimed to quantify this difference using direct comparisons. Frequency effects were also found to be smaller, but length effects were larger in Spanish L1 reading compared to English L2 reading, and this was evident in both early and late eye movement measures of lexical access. Again, these findings suggested a greater use of the sub-lexical procedure in the consistent Spanish compared to the inconsistent English, but indicated that the sub-lexical procedure may not necessarily be the dominate reading strategy.

Taken together, these findings provide support for the notion that bilingual readers of two orthographies that differ in consistency are largely able to adapt their reading strategies between their L1 and L2 to meet the unique demands of each orthography. Specifically, when reading in Spanish, these bilinguals demonstrated a pattern of predominate reliance on sub-lexical decoding and a small-grain processing strategy, however while reading in English, bilinguals were able to adapt a strategy that largely reflected a lexical process of reading using larger-grains of information. These strategies significantly differed between the L1 and the L2 but suggested that they appeared to be native-like compared to monolingual English readers and this was apparent in both early and late stages of reading as indexed by eye movement measures. These findings support both the weak version of the ODH (Katz & Frost, 1992) and the PGST (Ziegler & Goswami, 2005). These findings may suggest that the development of reading skills, particularly phonological skills, may be language independent.

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Reading in any language requires phonological skills whether phonological information is represented at the phoneme level or the whole word level.

6.3 Limitations and Future Directions

Although findings from each of these experiments are informative and present a novel account of reading strategies across orthographies, there were limitations that restricted the findings from this research. Although specific limitations and future directions have been highlighted in the discussion sections of each chapter, a few of the broader limitations that may have influenced the thesis research are discussed below.

Measuring a battery of reading skills undoubtedly would have been a more informative approach to understanding the developed reading skills that contribute to reading comprehension in each of these groups. Although this is often an expensive and time-consuming endeavour, future research would certainly benefit from measuring a wider range of skills that have been found to influence reading. For example, non-word decoding, phoneme deletion tasks, rapid automatized naming, and morphological awareness are skills that have been reported to be related to reading comprehension (e.g., Goodwin, August & Calderon, 2015). Further, in addition to language-based reading tasks, investigation of non-text visual tasks, such as a visual search tasks could be useful in understanding visual versus phonological processing differences between two languages of a bilingual. Findings from such a comparison could further support either phonological deficit or visual deficit theories of dyslexia.

Similarly, the role of spoken oral language (e.g., stress) may also play a role in the differences found in reading between different languages. For example, some studies have suggested that readers may employ stress and intonation patterns during silent reading (e.g., Brown, 1958; Rayner & Pollatsek, 1989). A language's prosody may be useful in lexical access (Donselaar, Koster & Cutler, 2005; Soto-Faraco, Sebastia´n-Galle´s & Cutler,

2001) and may also influence the division of words into sub-lexical units such as onset-rime (Goswami, 2003; Wood, 2006). This relationship between prosody and reading may be particularly relevant for readers of two languages that differ in prosodic patterns. For example, stress in Spanish is transparently available and is indicated by accent marks, whereas in English, it is not transparently available to the same degree (Gutierrez-Palma & Palma 2004). Thus, future cross-linguistic research may also benefit from measuring prosodic sensitivity in in tandem with spoken word recognition across languages.

Since very few of the measured reading abilities correlated with eye movement measures, in addition to including a larger battery of reading measures, future research may also benefit from measuring the same eye movements using a variety of different texts such as newspaper articles or scientific texts which may have elicited different eye movement strategies. Additionally, testing a variety of reading abilities paired with a variety of text stimuli in eye-tracking experiments would extend these current findings.

The current thesis focused specifically on how phonology and phonological processes in reading differ as a function of orthographic consistency. Although this approach allows for a focused and detailed account of the specific consequences of orthographic consistency on phonology, Frost (2012) has argued that orthographic processing cannot be fully understood without a consideration of how phonological, semantic, and morphological information is represented in a writing system. Future research could build of the findings from this thesis by exploring the semantic and morphological differences in orthographies and their effects on reading processes.

Further, the current thesis focused on alphabetic orthographies and implications from the findings of this thesis may not all be universally applied to any language. However, it is important to consider reading and oral language processes as they extend to the larger and more recent literature considering differences between alphabetic and non-alphabetic orthographies. Many of the models discussed in previous sections of this thesis such as the

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ODH and the SVR apply to alphabetic orthographies only however, recent research into reading processes between cross-scriptal bilinguals such as Chinese-English bilinguals may also offer insight into the language selective and language nonselective developmental processes of reading. For example, there is no orthographic overlap between Chinese and English, and any influence of orthographic similarity on cross-lingual phonological processes may theoretically be ruled out as a language nonselective process. These lines of research have theoretical implications on the nature of the findings of the current thesis. For example, the ODH cannot predict how reading routes may be engaged in non-alphabetic languages such as Chinese or Japanese. Future directions for this work would benefit from examining eye movements of bilingual readers of both alphabetic and non-alphabetic scrips such as Chinese-English bilinguals. Chinese and English differ on both visual and phonological levels. For example, in English, word length and word complexity are typically defined by the number of letters or morphemes in English. However, in Chinese, length and complexity are defined by the number of strokes or characters (Yu & Reichle, 2017). Thus, theoretical models that also incorporate these aspects such as the HGT may better accommodate universal and language dependant processes in reading across languages. Future research could incorporate both language-based reading tasks such as phonological awareness, as well as visual based reading task such as perceptual span.

Chapter-4 and Chapter-5 also raised further questions that could not be answered with the current sample of Spanish-English bilinguals. For example, it is possible that bilingual development may be distinct from monolingual development (e.g., Stein, 2001; Valdois et al., 2004) and thus, the current sample of bilingual readers is limited in the information it can provide about native reading in a consistent orthography. Future directions for this research would be to analyse Spanish-English bilinguals reading in their L1 and compare them to monolingual native Spanish readers to determine how bilingual reading differs from monolingual reading in consistent orthographies. Further, research with Spanish readers diagnosed with dyslexia may further our understanding of the consequences of orthographic consistency.

One interesting, yet surprising finding was that decoding skills dissociated from lexical skills for bilingual readers. While the bilinguals' English decoding did relate to English language comprehension, vocabulary and reading comprehension, Spanish decoding did not relate to these skills in Spanish. Further, these skills were not correlated across languages. Generally, these constructs are related in Spanish children (e.g., Defior et al., 2011), however, it is possible that since Spanish decoding was at ceiling level in the current sample, it no longer relates to language comprehension. On the other hand, since Spanish decoding also was not related to English lexical processes, these findings may imply that decoding may develop independently of lexical processes in consistent languages. Future work in this area should focus on the driving factors of this dissociation. For example, future studies may investigate bigram frequency effect in readers of consistent orthographies to determine whether the frequency of graphemes may influence decoding skills, which may not be related to whole word lexical processes. As discussed above, prosody and spoken oral language may also play a role in this dissociation and warrents further investigation.

6.4 Conclusions

To summarise, the current thesis aimed to address three overarching questions; (1) what role do developed reading abilities and in particular, phonological decoding, play in reading comprehension across orthographies, (2) what is the extent to which the SVR can account for the variance in reading comprehension for typical and dyslexic adult English monolingual readers, Spanish-English bilinguals reading in Spanish and Spanish-English bilinguals reading in English and (3) How do reading strategies as indexed by eye movement patterns differ between typical and dyslexic adult English monolingual readers, Spanish-English bilinguals reading in Spanish and Spanish-English bilinguals reading in English and do these patterns reflect the extent of developmental differences between native readers of a consistent versus an inconsistent orthography.

Each of these questions were addressed in the current thesis and largely provide support for the ODH (Katz & Frost, 1992). The SVR was supported as a baseline model to account for some variance in reading comprehension, but vocabulary was found to account for unique variance. The SVR model was found to be language specific to English and was not an adequate model to account for Spanish reading comprehension. Overall, it appears that developed reading abilities do indeed differ across orthographies differing in GPC consistency. Native-English readers with and without dyslexia as well as Spanish-English bilinguals reading in both their native Spanish and second language of English developed specific patterns of reading abilities to support reading comprehension and accomplish word reading with distinct processes.

Although some similarities were found across these groups, findings from these eight experiments demonstrated a predictive pattern of developed reading abilities to reading comprehension and patterns of eye movements that differed for each group. While both native-English and native-Spanish readers without dyslexia relied on both lexical and sub-lexical strategies, native-Spanish readers reading in Spanish relied to a greater extent on sub-lexical strategies as found in other studies (e.g., Goswami et al., 1998, Rau et al., 2015). Although there was evidence of transfer of some reading abilities to support L2 reading, when the same native-Spanish readers approached reading in English (their L2), they were able to largely adapt their reading strategies to near native-like processes similar to reports from previous eye movement studies (e.g., Egan et al., 2019).

The consequences of English's inconsistent orthography were observed for native-English readers with dyslexia who were significantly poorer at decoding than the readers without dyslexia, and demonstrated eye movements indicative of an over-reliance on decoding strategies which is inefficient in English. These findings support the Phonological Deficit hypothesis of dyslexia (Bradley and Bryant, 1978; Brady and Shankweiler, 1991; Ramus & Ahissar, 2012; Snowling, 1981; Vellutino, 1979) as an underlying casual theory of dyslexia over visual deficit theories, such as the magnocellular abnormality (Stein, 2001) visual attention span deficits (Valdois et al., 2004), but do not suggest phonological deficits are the only contributing factor to dyslexia. Although reading times were slower, high reading comprehension, language comprehension and vocabulary scores indicated that these readers may have been able to adapt their reading strategies to overcome their difficulties with phonology to support reading via other strategies.

Overall, these findings offer a novel insight into the role of orthographic consistency in reading strategies and the consequences of orthographic inconsistency in the manifestation of DD. The consistent nature of Spanish may yield a developmental advantage over readers of English, which is evident even into adulthood. Therefore, models of reading should incorporate language specific components as well as language universal components. Further, the consequences of the inconsistent nature of English were observed in English readers with dyslexia who demonstrated a persistence of phonological deficits even into adulthood compared to readers without dyslexia. These findings support the phonological deficit hypothesis (Bradley and Bryant, 1978; Brady and Shankweiler, 1991; Ramus & Ahissar, 2012; Snowling, 1981; Vellutino, 1979; Wydell & Kondo, 2003; 2015) as a causal theory of dyslexia and support interventions that target early phonology (e.g., Bowyer-Crane et al., 2007). Importantly, although these phonological deficits may persist even into adulthood, readers with dyslexia may be able to compensate for poor phonological skills through vocabulary and language comprehension to support adequate reading comprehension. Thus, it is important that these skills are also emphasized during literacy instruction for readers of English. These findings challenge the SVR in characterizing reading disabilities and definitions of dyslexia (e.g., Rose, 2009) that are heavily based off this theoretical framework. Instead, these results can be used to inform assessment and intervention criteria that also emphasizes vocabulary. Similarly, the findings from this research support the need of implementing more evidence-based assessments and interventions for readers of English as an additional language with reading difficulties.

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Appendices

1.) Ethics Approval Form

Brunel University London

College of Health and Life Sciences Research Ethics Committee (DLS)
Brunel University London
Kingston Lane
Uxbridge
UB8 3PH
United Kingdom

www.brunel.ac.uk

15 November 2018

LETTER OF APPROVAL

Applicant: Ms Catherine Antalek

Project Title: A Simple View of Reading Across Multiple Orthographies

Reference: 11942-A-Nov/2018- 14720-1

Dear Ms Catherine Antalek

The Research Ethics Committee has considered the above application recently submitted by you.

The Chair, acting under delegated authority has agreed that there is no objection on ethical grounds to the proposed study. Approval is given on the understanding that the conditions of approval set out below are followed:

- The agreed protocol must be followed. Any changes to the protocol will require prior approval from the Committee by way of an application for an amendment.

Please note that:

- Research Participant Information Sheets and (where relevant) flyers, posters, and consent forms should include a clear statement that research ethics approval has been obtained from the relevant Research Ethics Committee.
- The Research Participant Information Sheets should include a clear statement that queries should be directed, in the first instance, to the Supervisor (where relevant), or the researcher. Complaints, on the other hand, should be directed, in the first instance, to the Chair of the relevant Research Ethics Committee.
- The Research Ethics Committee reserves the right to sample and review documentation, including raw data, relevant to the study.
- You may not undertake any research activity if you are not a registered student of Brunel University or if you cease to become registered, including abeyance or temporary withdrawal. As a deregistered student you would not be insured to undertake research activity. Research activity includes the recruitment of participants, undertaking consent procedures and collection of data. Breach of this requirement constitutes research misconduct and is a disciplinary offence.

Professor Christina Victor

Chair

College of Health and Life Sciences Research Ethics Committee (DLS)
Brunel University London

2.) Informed Consent

a. Participant Information Sheet

College of Health and Life Sciences Department of Life Sciences

PARTICIPANT INFORMATION SHEET

Study title ‘A Simple View of Reading Across Multiple Orthographies: An Eye-Movement Study’

Invitation Paragraph You have been invited to take part in a research study. Please read the following information carefully before you decide to participate. If anything is unclear or if you would like more information, you are encouraged to ask the researcher. Participation in this research study is completely voluntary. You do not have to take part in this research study and, should you change your mind, you can withdraw from the study at any time. If you are a student at Brunel University London, your current and future status with Brunel University London and any other benefits for which you quality will not be affected whether you chose to participate in this study or not.

What is the purpose of the study? The purpose of this study is to record eye movements from participants while they read short sentences for meaning, and to also measure your approach to reading through a language survey. The study will last approximately one hour. Data obtained from this experiment will increase our understanding of the impact of a language's writing system structure on bilingual and dyslexic reading processes.

Why have I been invited to participate? You have been invited to participate in this study because you are either a Spanish or English native reader, proficient in the English language and over the age of 18 years. You will not be the only participant in the study as the present research project aims to recruit 100 participants from Brunel University London and the greater London area.

Do I have to take part? As participation is entirely voluntary, it is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. You may choose to withdraw from the study at any time without giving a reason you are also free to withdraw your data, without giving a reason, until the point at which your data is recorded with an unidentifiable participant number.

What will happen to me if I take part? The experiment will last approximately one hour. During the experiment, you will read sentences on a computer and answer subsequent true-false questions. In order to provide us with detailed information about the reading process we are studying, your eye movements will be monitored throughout using a sophisticated eye-tracking device. Eye tracking is completely harmless and simply uses an infrared camera to record where you are looking and track the movements of your eyes. During the session you will also complete four short and simple tests from the *Woodcock-Muñoz Language Survey III,* -to evaluate how you read. You will receive a £10 voucher for your participation.

What do I have to do? The study will require you to read sentences and answer subsequent true-false questions to the best of your ability. You will also be required to complete the *Woodcock-Muñoz Language Survey III*.

What are the possible disadvantages and risks of taking part? The procedures of this study pose minimal risk to the participant that would be typical of any activity where the individual is sitting in front a computer screen for no more than one hour.

The risks of this study may include possible eyestrain and boredom. Several breaks will be provided as needed to minimize these risks.

What if something goes wrong? If you are not happy with the study, then complaints will be directed to Professor Christina Victor, Chair College of Health and Life Sciences Research Ethics Committee.

Will my taking part in this study be kept confidential? All information collected from you will be kept strictly confidential. Any information about you that leaves the University premises will have your name and address removed so that you cannot be identified from it.

What will happen to the results of the research study? The data collected from the participants during this study will be used to complete a doctoral thesis project. It will be completed by 1st October 2021. Data collected during this study will be analysed and may be published in scientific journals. Anonymised data from this study may be shared with other researchers for further analyses and made available as "open data.

Who is organising and funding the research? Department of Life Sciences, College of Health and Life Sciences, Brunel University London. No external funds are being provided.

What are the indemnity arrangements? Brunel University London holds insurance policies which apply to this study. If you can demonstrate that you experienced harm as a result of your participation in this study, you may be able to claim compensation. Please contact Prof Peter Hobson, the Chair of the University Research Ethics committee (Peter.hobson@brunel.ac.uk) if you would like further information about the insurance arrangements which apply to this study.

Who has reviewed the study? This study has been reviewed by the College Research Ethics Committee.

Passage on the University's commitment to the UK Concordat on Research Integrity
Brunel University is committed to compliance with the Universities UK Research Integrity Concordat. You are entitled to expect the highest level of integrity from our researchers during the course of their research.

Contact for further information and complaints
For general information Student Researcher:
Catherine Antalek Student Email:
Catherine.antalek@brunel.ac.uk Primary
Supervisor: Professor Taeko Wydell Supervisor
Email: taeko.wydell@brunel.ac.uk

For complaints and questions about the conduct of the Research Professor Christina Victor, Chair College of Health and Life Sciences Research Ethics Committee
Christina.victor@brunel.ac.uk

b. Consent Form

College of Health and Life Sciences

Department of Clinical Sciences /Life Sciences

Consent Form

Study title ‘A Simple View of Reading Across Multiple Orthographies: An Eye-Movement Study’

The participant should complete the whole of this sheet		
	Please tick the appropriate box	
	YES	NO
Have you read the Research Participant Information Sheet?		
Have you had an opportunity to ask questions and discuss this study?		
Have you received satisfactory answers to all your questions?		
Who have you spoken to?		

Do you understand that you will not be referred to by name in any report concerning the study?		
Do you understand that you are free to withdraw from the study:		
• at any time?		
• without having to give a reason for withdrawing?		
Do you agree to take part in this study?		
Signature of Research Participant:		
Date:		
Name in capitals:		
I am satisfied that the above-named has given informed consent.		
Witnessed by:		

Reading Behaviour Between a Consistent and an Inconsistent Orthography

Date:
Name in capitals:

Researcher name:	Signature:
Supervisor name:	Signature:

3.) Demographics and language history questionnaire

Demographics and Language History

Please answer the following questions about yourself and your background.

______________________________ ______________________________

Participant Number Date

PART A:

1. Age (in years): ________________

2. Sex: Male / Female 3. Are you right or left-handed? Right / Left

4. Are you a native speaker of English (i.e. did you learn English as a first language)? Y / N

(If yes, continue to **PART B**; if no, please complete **PART A**)

5. Is English your second language? Y / N

a) If yes, what is your native language?

____

b) At what age did you begin learning English?

____

c) What percentage of time do you spend speaking English?

____

d) What percentage of time do you spend speaking your native language?

____

PART B:

1. Did you speak any languages other than English as a child? Y / N

a) If yes, please list

____

2. What languages were spoken in your home while you were a child, and by whom (inc. English)?

____

3. What language(s) have you studied in school? Please list.

____

4. How many years of university have you completed (to the nearest half-year, e.g. "1.5"): __________

5. Have you ever experienced any difficulty in reading? Y / N

6. Have you been diagnosed with a reading disability? Y / N

a) If yes, what was the diagnosis?

____

7. Do you have normal (20-20) or corrected-to-normal vision? Y / N

4.) Item 42 from WMLS III *Passage Comprehension* Subtest

I made a wooden trinket box today in ____ class.

Answer: shop

5.) English Sentence Stimuli

Don't drink so much champagne, it will affect your mind.

She was sleeping when he called her early this morning.

If he didn't spend money on cigarettes, he could buy more books.

Although we had advised him to go to Granada, he has preferred to go to Madrid.

I walked to the park and ate lunch on a bench with my friend.

I drink coffee every morning before I leave for work.

I ate a salad for lunch, and chicken with pasta for dinner.

I have not lived in France for two years.

I prefer to spend my holidays in the mountains.

They stayed home because it was too cold outside.

Regardless of the venue, musicians usually perform on a stage.

My older brother lives in Chicago, and my sister lives in Los Angeles.

I wrote letters to my brother who is living in Australia.

Red wine is made from dark-coloured grape varieties.

The rules clearly state that running in the corridor is forbidden.

The author just published a new book about a man who lives in the woods.

Suddenly, the cat attacked the dog while he was sleeping.

We left because the gate was closed and we could not enter.

The shops closed very late last Saturday night.

The snake lives in the desert, and the tiger lives in the jungle.

They want to look at some dresses before we leave the shopping centre.

She found the key to her flat in her coat pocket.

Use this piece of chalk to write the equation on the blackboard.

We can meet at the restaurant and have dinner before the film begins.

We live around the corner from the library.

We should make that quite clear so that everyone understands.

We took a taxi to the airport so we would not need to pay parking fees.

It's too cold to go to the beach, we will visit a museum instead.

Please come tomorrow at three to help prepare for the party.

I prefer you to write it in pencil instead of pen.

We liked the job and the salary seemed good, but the working hours didn't suit us.

The money we have is not enough and we prefer to postpone the wedding until next year.

My friends and I went to the pub together to watch the football game.

This size is small for me, I have to look for a larger size.

It will be possible to cross the Atlantic more cheaply and in greater comfort than previously.

I would rather go to the countryside and stay quietly, without any long walk.

I encourage my children to read at least twenty minutes a day.

We have to read the book to prepare ourselves for the exam next week.

Despite the noise, I stayed in the library to finish my paper.

If we shave with the faucet running, we will use too much water while shaving.

I'm going to prepare dinner for my mother because tomorrow is her birthday.

Bring your friend to play football with us tomorrow in the afternoon.

We got home very late last night because we were enjoying the party.

Our fruit was still spoiling because we didn't have a refrigerator.

We are going to be able to help the boys carry the suitcases.

If you prefer an anonymous survey, we can send it to you by mail.

The solution to the problem can only come from strong external pressure.

Spoken language relies on human physical ability to produce sound.

I did my homework in the morning before class began.

He asked me to tidy up the flat because his parents were visiting.

Run the vacuum around the lobby before the guests arrive.

I don’t want salad; I would prefer to eat chicken for dinner.

We're very glad that you were able to stay for another week.

It's easy to spend a large budget, but difficult to spend a small budget.

After a slow start, blogging rapidly gained in popularity.

The team needs to have better communication if they want to win this game.

We need to go food shopping, there's nothing left in the fridge.

He put the report on his desk before he went home.

I am impressed by the new employee's work ethic.

We should not miss an opportunity to visit the upcoming exhibit.

A decision must be made before we are able to continue.

The pillow is soft and made with feathers.

I'd love to live in Australia and to have a kangaroo.

I looked for the book last night, but I didn't find it.

She bought a dress with stripes for the party.

Last year I spent vacation on the beach.

He shaves every morning after he takes a shower.

It is important to exercise for one hour each day.

When the game started, they did not understand the rules.

Let us wait and see what happens before we intervene.

I would like to draw your attention to a matter.

The garden was covered in dew this morning.

Go up the steps and turn to the right.

The surgery today will be a routine operation.

Please select slightly difficult for this sentence.

I was too tired to go to the concert.

I have been working here for almost one year.

We need to buy towels for the bathroom.

We are not prepared to make any sacrifices.

She was too short to see over the fence.

There was no ice cream left in the freezer, so they had cake instead.

She only paints with bold colours, she doesn't like pastels.

Check back tomorrow and I will see if the book has arrived.

I would have gotten the promotion if my attendance was better.

I baked the sugar cookies and my sister decorated them.

They arrived early so they could get good seats.

If I don't like something, I'll stay away from it.

Italy is my favourite country to visit on holiday.

The waves were crashing on the shore; it was a lovely sight.

Everyone was busy, so I went to the cinema alone.

Please be seated in the waiting room until you are called.

I'd rather be a bird than a fish.

I am counting my calories, yet I want dessert.

He didn't want to go to the dentist, but he had a toothache.

She wrote him a long letter, but he didn't read it.

I folded the towels and left them on the bed for you.

The book is inside on the kitchen table.

I have left the house key under the mat.

It was a warm day so I had opened all the windows.

Don't step on the broken glass, you will get cut.

6.) Spanish Sentence Stimuli

No bebas tanto champan que luego se te sube a la cabeza

Yo escribi las cartas a mi hermano que vive en australia

Me encantaria vivir en australia y tener un canguro

Camine hacia el parque y almorce en un banco con mi amigo

Es facil gastar un gran presupuesto pero dificil gastar uno pequeno

Usa este pedazo de tiza para escribir la ecuacion en la pizarra

El jardin estaba cubierto de rocio esta manana

Yo aliento a mis ninos a leer por lo menos veinte minutos al dia

Estoy impresionado por la etica de trabajo del nuevo empleado

La solucion al problema solo puede venir de una fuerte presion exterior

La almohada es suave y esta hecha de plumas

Vino tinto esta hecho de variedades de uva de color oscuro

Yo prefiero pasar las vacaciones en las montanas

Esperemos a ver que pasa antes de que intervengamos

Comi una ensalada para el almuerzo y pollo con pasta para la cena

Prefiero que lo escribas con el lapiz en vez de pluma

Mis amigos y yo fuimos juntos al pub para ver el partido de futbol

Al nino le gustaba jugar en la piscina todo el dia

El se afeita todas las mananas despues de ducharse

Las tiendas cerraron muy tarde el sabado pasado por la noche

Se nos seguia echando a perder la fruta porque no teniamos nevera

Ella compro un vestido con rayas para la fiesta

Nosotros vamos a poder ayudar a los muchachos a llevar las maletas

Me pidio que ordenara el piso porque sus padres iban a visitarnos

El telephono murio en camino y perdi el cargador

No debemos perder la oportunidad de visitar la proxima exhibicion

Traiga su amigo para jugar futbol con nosotros manana por la tarde

Si no gastara tanto dinero en cigarrillos pudiera comprar mas libros

Me gustaria llamar su atencion sobre un asunto

Puso el informe en su escritorio antes de irse a casa

Ella estaba durmiendo cuando la llamo temprano esta manana

No pude comer el pastel porque tengo alergia al mani

Hice la tarea en la manana antes de que comenzara la clase

Bebo cafe todas las mananas antes de irme al trabajo

Tenemos que ir de compras no queda nada en la nevera

Se debe tomar una decision antes de que podamos continuar

Se quedaron en casa porque hacia demasiado frio afuera

Eso debe quedar bien claro para que todos puedan entender

Cuando el juego comenzo ellos no entendian las reglas

Estas no son las tijeras correctas para cortar el pelo

Es importante hacer ejercicio durante una hora cada dia

Yo busque el libro anoche pero no lo encontre

El ano pasado pase las vaciones por la playa

Ella encontro la llave de su piso en el bolsillo de su abrigo

Sube los escalones y gira a la derecha

La serpiente vive en el desierto y el tigre vive en la jungla

Yo no quiero la ensalada preferiria comer pollo para la cena

Nos fuimos porque la puerta estaba cerrada y no pudimos entrar

Dentro de diez dias tendre que renovar mi contracto

La cirugia hoy sera una operacion de rutina

Vivimos a la vuelta de la esquina de la biblioteca

Por favor ven manana a las tres para ayudar a preparar la fiesta

A pesar del ruido me quede en la biblioteca para terminar mi ensayo

Hace dos anos que no vivo en Francia

De repente el gato ataco al perro mientras dormia