THE ROLE OF CONTEXTUAL INFORMATION IN EXPERT ANTICIPATION

COLM PÁDRAIG MURPHY

A thesis submitted for the degree of Doctor of Philosophy

Department of Life Sciences,

Brunel University London

July 2017

Contents

Acknowledgements

I could not possibly attempt to mention here, every single person who has helped me over the past few years. I can only say, with the greatest sincerity, to everyone who has played a role, no matter how big or small that role may have been, thank you. However, I would particularly like to express my gratitude to some key people, without whom this would not have been possible.

I count myself incredibly lucky to have been supervised by true experts in the field and I appreciate every minute they have spent guiding me through the PhD process. I would like to thank Professor Mark Williams for taking everything he knows about skill acquisition and applying it to PhD supervision with the greatest efficiency, for providing me with endless opportunities, priceless advice and perfectly timed encouragement. Dr Robin Jackson for his equally priceless advice, invaluable guidance and impressive patience. I am sure at times he cursed his open door policy but never once showed it. Dr Dan Bishop, for his support and assistance on the (relatively long) home straight. To those who facilitated data collection and everyone who acted as a participant, I cannot express my gratitude enough for the time and energy they committed.

Equally as importantly, there are certain people in my personal life who I would like to thank for supporting me throughout this long journey. Melissa, for being with me every single step of the way. We have been on many adventures together but without her, this one would not have been remotely possible. Her persistent encouragement has been awesome. My parents, for providing me with the tools to choose the path I wanted to. All my family, for their unwavering support and abundant understanding. Finally, my friends, for being exactly that. Thanks everyone.

List of Publications and Presentations

Publications

Murphy, C. P., Jackson, R. C., & Williams, A. M. (2018). The role of contextual information during skilled anticipation. *Quarterly Journal of Experimental Psychology.*

Murphy, C. P., Jackson, R. C., Cooke, K., Roca, A., Benguigui, N., & Williams, A. M. (2016). Contextual information and perceptual-cognitive expertise in a dynamic, temporally-constrained task. *Journal of Experimental Psychology: Applied, 22*, 455-470.

Conference Proceedings

Murphy, C. P., Jackson, R. C., & Williams, A. M. (2016). The effect of sequencing information on anticipation. *Journal of Sport and Exercise Psychology, 38,* S90.

Murphy, C. P., Jackson, R. C., & Williams, A. M. (2015). Perceiving context: The key to anticipation in sport? In O. Schmid, S. Seiler (Eds.) *14th European Congress of Sport Psychology Bern, Switzerland,* 154.

Murphy, C. P., Jackson, R. C., Roca, A., & Williams, A. M. (2015). Cognitive processes underlying anticipation in a context-oriented task. *Journal of Sport and Exercise Psychology, 37,* S53.

Murphy, C. P., Jackson, R. C., & Williams, A. M. (2014). The use of contextual information in expert tennis anticipation. In A. De Haan, C. J. De Ruiter, E. Tsolakidis (Eds.) *19th Annual Congress of the European College of Sport Science, Amsterdam, The Netherlands.*

List of Figures

Abstract

While it is well established that expert performers can pick up and utilise postural cues to anticipate more effectively than less-skilled counterparts, the role of contextual information in expert anticipation has received relatively little research attention. The aims of this thesis were to highlight the importance of contextual information in anticipation, identify specific sources of contextual information that impact anticipation, and examine how this information is used. In five studies, skilled and less-skilled tennis players were presented with videos or animations of the same open play rallies. The animations omitted postural information, constraining participants to anticipate based on contextual information alone. First, participants anticipated more accurately than chance in both display conditions. Skilled participants were more accurate than less-skilled participants, with the difference being greater in the video condition. Second, gaze data and retrospective verbal reports were collected when viewing the animations. Skilled participants displayed different gaze behaviour and more thoroughly evaluated the presented information than less-skilled participants. Third, animations were manipulated to depict or omit potential sources of contextual information. The preceding shot sequence was shown to be a useful source of contextual information, particularly for skilled participants. Additionally, player positioning could be used to anticipate highly accurately in absence of any other information. Finally, the option generation strategies underpinning expert anticipation were examined. Participants generated fewer options when postural cues were available compared with when constrained to the use of contextual information alone. Moreover, skilled participants generated more task-relevant and fewer task-irrelevant options than less-skilled participants. Collectively, these findings increase understanding of the role of contextual information in expert anticipation and further highlight the complex nature of perceptual-cognitive expertise.

Chapter 1

Perceptual-cognitive expertise and an introduction to the role of contextual information in anticipation

It is difficult not to be fascinated by the amazing behaviour and feats of expert performers. There is perhaps no other domain in which the superiority of experts is more easily apparent than sport. At the highest levels, expert athletes can not only execute actions with phenomenal speed and accuracy, but they can respond to the equally quick and accurate actions of their opponents whilst giving the impression of having "*all the time in the world*". The competitive nature of sport means that it is rife with individuals striving for excellence and constantly pushing the boundaries of human performance in an attempt to become the best. It therefore provides a particularly fruitful domain within which to conduct research that allows us to move beyond the realms of fascination, towards a fuller understanding of the essential skills and attributes of expert performance as well as the underlying processes and mechanisms (Williams, Ford, Eccles, & Ward, 2011). Knowledge gained from this field of research can be used to develop and adapt existing theoretical models of skill acquisition and expertise, both in sport and in domains such as medicine and education (Farrow, Reid, Buszard, & Kovalchik, 2017; Williams & Ericsson, 2005), as well as providing important implications for training interventions and talent identification and development programmes (Ericsson & Ward, 2007; Williams & Reilly, 2000).

For over a century, there has been debate about what distinguishes expert performers from their less-expert counterparts. The early research findings of Sir Francis Galton (1869) suggested that expertise is determined by an individual's innate ability and motivation, a view which was widely held for many years with few exceptions (e.g., Watson, 1924). Given the perceived importance of an individual's genetic make-up in determining expertise, researchers invested great effort in identifying and describing the innate characteristics and abilities underlying skilled performance (e.g., Ackerman, 1988; Fleishman, 1972; Terman & Oden, 1959).

Early research findings suggested that expert sports performance was underpinned by superior visual attributes (e.g., Fullerton, 1921). However, more recent research has led to a general consensus that expert sports performance is not limited by basic visual functions such as visual acuity and depth perception (e.g., Abernethy, 1987; Abernethy, Neal, & Koning, 1994; Helsen & Starkes, 1999; Starkes & Deakin, 1984; Ward & Williams, 2003). Many of these researchers have employed multivariate analyses to determine the degree of the variance between expert and less-expert performers which can be accounted for by tests of vision, perception and cognition. Rather than measures of visual function, it is measures of perceptual-cognitive skills such as anticipation and decision making that consistently account for a large proportion of the variance (e.g., Abernethy et al., 1994; Ward & Williams, 2003). Mann and colleagues recently presented further evidence against the notion that superior vision is a limiting factor of expert performance (Mann, Ho, De Souza, Watson, & Taylor, 2007; Mann, Abernethy, & Farrow, 2010a, 2010b; see also Applegate & Applegate, 1992). Using a visual blurring technique to degrade the visual clarity of skilled cricket batters, Mann et al. demonstrated that substantial decrements in visual clarity, in some cases to a level comparable to legal blindness, were necessary for batting performance to be negatively affected.

Expertise

It was through the seminal research of de Groot (1965) and later, that of Chase and Simon (1973) that some of the earliest evidence emerged to suggest that expertise results from the development of domain-specific skills rather than innate individual differences. De Groot (1965) presented chess players of various levels with structured configurations of chess pieces for a short period of two to 10 seconds. After having withdrawn these pieces from sight, participants were asked to recall the positions of the pieces from memory. Chess Grand Masters and Masters were able to reproduce the positions of these pieces with approximately 93% accuracy. However, in the three progressively lower classified skill levels, recall accuracy drastically decreased (approximately 72%, 51% and 33%).

Chase and Simon (1973) extended this research by asking participants to recall structured configurations of pieces extracted from games between advanced chess players, as well as configurations of pieces which had been randomly arranged on the board. When structured configurations were presented, their findings were comparable with those of de Groot (1965). However, of particular significance is that when required to recall the pieces presented in random configurations which would not usually be observed in a chess match, the Master was no more accurate than the A level or Club level player. It could therefore be concluded that the Master's superior performance when recalling the structured configurations was not due to greater visual short term memory (STM) capacity (which would have been evidenced by more accurate recall regardless of the structure of the configurations). The differences in recall in the structured condition alone must have been due to the context provided by the positions of the chess pieces. Viewing these familiar configurations which the Master would have frequently experienced and engaged with previously facilitated superior recall, this process made possible by a more extensive, domain-specific knowledge base.

Chase and Simon (1973) proposed a "chunking" mechanism to explain the superior recall of expert chess players. They suggested that when the configurations were structured, the more expert chess players were able to perceive this structure and encode large numbers of pieces (15-30) into meaningful chunks, rather than needing to encode pieces one by one, which would soon exceed the capacity of STM (7 ± 2 items; Miller, 1956). While 'chunking' increases the amount of information which could be encoded to circumvent the limitations of STM, the proposed mechanism nevertheless functions within the limitations of STM in that the number of chunks, cannot exceed the capacity of STM. Since the seminal work of de Groot (1965) and Chase and Simon (1973), the ability of expert performers to encode and recall domain-specific patterns has been observed in multiple sports such as basketball (Allard, Graham, & Paarsalu, 1980; Gorman, Abernethy, & Farrow, 2012) field hockey (Starkes & Deakin, 1984), football (Williams, Davids, Burwitz, & Williams, 1993; van Maarseveen, Oudejans, & Savelsbergh, 2015) and handball (Tenenbaum, Levy-Kolker, Bar-Eli, & Weinberg, 1994), as well as in other domains such as computer programming (Adelson, 1981), electronics (Egan & Schwartz, 1979) and map reading (Gilhooly, Wood, Kinnear, & Green, 1988).

Although Simon and Chase (1973) acknowledge that their research did not directly address how expertise is developed, they did suggest a minimum of ten years' practice in chess would be necessary to become a Grand Master. Other researchers in later years echoed this proposal, agreeing that extensive preparation of approximately ten years or more is a common requirement for attaining expertise in many sports and in other domains (e.g., Bloom, 1985; Ericsson & Crutcher, 1990). Ericsson, Krampe, and Tesch-Romer (1993) reiterated this point in their deliberate practice framework. They suggested that through engagement in large amounts of domain-specific practice, it is possible to develop the cognitive skills necessary to circumvent the limits of STM capacity, which facilitate expert performance.

Ericsson and Smith (1991) criticised early approaches as attempts to independently measure constructs that were *thought* to be factors underpinning expertise, rather than describing and subsequently analysing the components that contribute to expert performance in standardised conditions. The pioneering work of de Groot, Chase, and Simon provided the foundations for Ericsson and Smith to outline the expert performance approach, a three-stage systematic framework for empirically examining expertise (see Figure 1.1).

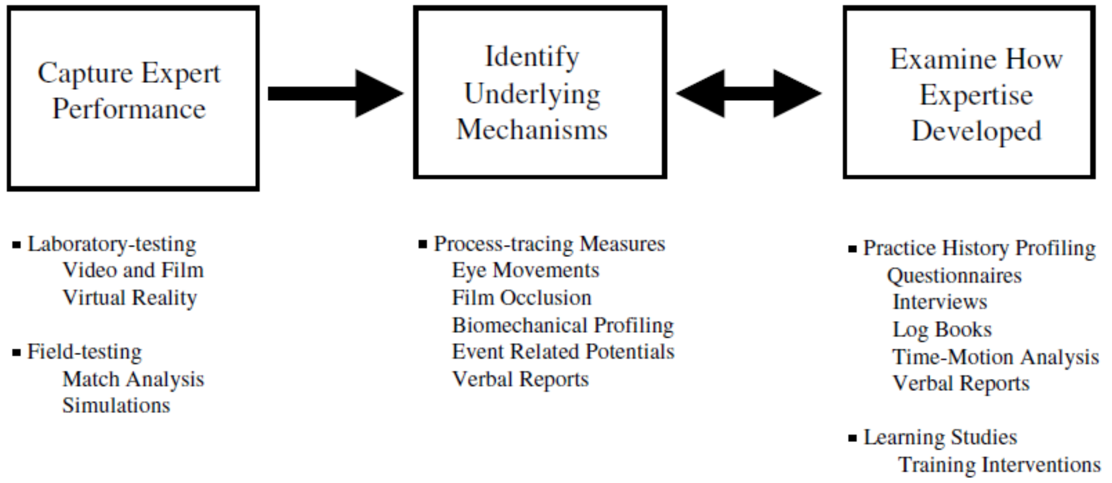


Figure 1.1. The three stages of Ericsson and Smith's (1991) expert performance approach[1].

Taking this approach, researchers first design tasks to capture expert performance in the laboratory or field. Advances in technology have made this increasingly possible with expert performance now consistently being captured using standardised tasks in laboratory settings (e.g., McRobert et al., 2013; Spitz, Put, Wagemans, Williams, & Helsen, 2016). Second, the processes and mechanisms underlying expert performance are identified. Tasks manipulations (e.g., film occlusion, displaying information in point-light format) and process-tracing methods (e.g., gaze tracking, verbal report analysis) are commonly employed at this stage (e.g., Abernethy, Zawi, & Jackson, 2008; McRobert, Williams, Ward, & Eccles, 2009). Finally, the key acquisition processes associated with expertise development are investigated. Practice history profiling and training interventions have proven instrumental in providing evidence of the practice activities

[1] Reprinted from Human Movement Science, 24, Williams, A. M., & Ericsson, K. A., Perceptual-cognitive expertise in sport: Some considerations when applying the expert performance approach, p. 286, 2005.

and environmental factors that contribute to expert performance (e.g., Broadbent, Causer, Ford, & Williams, 2015; Roca, Williams, & Ford, 2012).

Perceptual-cognitive expertise

Perceptual-cognitive skill is an individual's ability to identify and acquire environmental information for integration with existing knowledge such that an appropriate response can be selected and executed (Marteniuk, 1976). It is now widely acknowledged that some of the most important adaptations resulting from extended experience and practice in a particular domain are in the perceptual and cognitive skills underpinning performance (Baker & Farrow, 2015; Williams & Ford, 2008). This is not to discount the importance of physiological components of performance, but rather to note that perceptual-cognitive skills such as anticipation and decision making have been demonstrated to account for a greater proportion of the variance between the performance of experts and less-expert counterparts (Williams & Reilly, 2000).

While the importance of perceptual-cognitive skills in domains such as military combat (Williams, Ericsson, Ward, & Eccles, 2008), medicine (Krupinski, 2000; McRobert et al., 2013), driving (McKenna & Horswill, 1999; Underwood, 2007), and law enforcement (Ward, Suss, Eccles, Williams, & Harris., 2011) is indisputable, there are perhaps few domains in which the importance of such skills is as prominent or as obvious as in sport. In tennis, for example, service speeds can reach over 200 $km \cdot h^{-1}$ (Mecheri, Rioult, Mantel, Kauffmann, & Benguigui, 2016) with the distance between the two players being roughly 24 m at the moment the ball is struck. It can therefore take less than 500 ms from the moment the ball leaves the opponent's racket to reach, and potentially pass, the receiving player (Abernethy & Wollstein, 1989). Similarly tight time constraints can be observed in other fast ball sports such as cricket (Regan, 1997), baseball (Gray, 2002a), and football (Dicks, Button, & Davids, 2010). Such constraints provide researchers with an ideal domain in which to investigate how expert performers circumvent information processing limitations to perform effectively (Moran, 2009). It is generally accepted that, due to extensive experience and practice in their domain, expert performers develop more extensive knowledge bases than less-expert performers, and that these knowledge bases allow experts to more effectively attend to and interpret relevant information in the environment to anticipate upcoming events (Mann, Williams, Ward, & Janelle, 2007). In the following sections, descriptions of some of the specific perceptual-cognitive skills proposed to underpin expert anticipation are presented.

Postural cue utilisation

The ability to pick up and utilise relevant information from an opponent's bodily movements and postural orientation to anticipate their intentions in advance of a critical event (e.g., racket-ball contact in tennis) has proven to be a reliable discriminator between expert and less-expert performers (e.g., Causer, Smeeton, & Williams, 2017; Goulet, Bard, & Fleury, 1989; Moore & Müller, 2014). Researchers originally demonstrated this skill through expert-novice comparisons on tasks employing the temporal occlusion paradigm. Employing this method, researchers usually present participants with video footage of the opponent executing an action. These videos are edited to selectively occlude at various time points prior to, at, or following the critical event. Using this approach, Jones and Miles (1978) demonstrated that tennis players could anticipate the direction of an opponent's serve in advance of ball flight information becoming available and that skilled players were more accurate than less-skilled counterparts when anticipating the opponent's intentions prior to racket-ball contact. The expert advantage in picking up and utilising postural cues to anticipate the opponent's intentions has since been reproduced in a variety of sports (e.g., Abernethy & Russell, 1987; Rosalie &

Müller, 2013; Starkes, 1987; Williams, 2000). Researchers employing this paradigm have further demonstrated that observed skill differences are more pronounced when vision is occluded earlier in the opponent's movement (e.g., Müller, Abernethy, & Farrow, 2006; Tenenbaum, Levy-Kolker, Sade, Lieberman, & Lidor, 1996; Williams & Burwitz, 1993), suggesting that experts develop the ability to pick up specific early-occurring cues to overcome information processing limitations in situations of extreme time constraints.

While the temporal occlusion paradigm has been employed to determine the time point at which critical information becomes available, the spatial occlusion paradigm has been employed to determine the specific postural cues used to anticipate the opponent's intentions. Using this approach, researchers selectively occlude certain areas of the visual display or alternatively present only certain areas for the duration of the action up until the moment of the critical event (Abernethy & Russell, 1987; Hagemann, Schorer, Cañal-Bruland, Lotz, & Strauss, 2010; Jackson & Mogan, 2007). If performance drops significantly when a certain area of the body or equipment is occluded from the visual display (in comparison to a control condition without occlusion), it can be assumed that this area provides pertinent postural cues to the performer. More recently, researchers have combined temporal and spatial occlusion methods to determine the time point at which specific cues are extracted in anticipation (Causer et al., 2017; Müller et al., 2010). Although the information sources relied upon vary between sports, experts have generally been shown to pick up earlier-arising cues from more proximal information sources (e.g., the hips in football [Causer et al., 2017] and the trunk in fencing [Hagemann et al., 2010]) than less-skilled athletes who rely more on later-occurring, more distal information.

Based on research examining biological motion perception (e.g., Johansson, 1973, Kozlowski, & Cutting, 1977; Shim & Carlton, 1997), employment of the point-light method has been instrumental in determining the nature of the information which facilitates anticipation. This method involves presenting participants with point-light displays (usually white dots of light on a black background or vice-versa) of an opponent executing an action in which the depicted information has been reduced to minimal biological motion information. Although a slight drop in performance is usually observed when viewing point-light displays in comparison to videos, the skill differences observed in studies employing the temporal and spatial occlusion paradigms are generally replicated when point-light displays are presented rather than videos (e.g., Abernethy, Gill, Parks, & Packer, 2001; Abernethy & Zawi, 2007; Abernethy et al., 2008). Several researchers have interpreted this finding as meaning that the information facilitating expert anticipation is picked up from the relative motion between specific body parts or equipment rather than isolated body parts or superficial features.

Experts have been shown to more effectively and efficiently scan and subsequently fixate on more informative areas of the visual display to pick up pertinent postural cues when anticipating an opponent's intentions (Mann et al., 2007). This effect has frequently been demonstrated via skill-based differences in the number of locations fixated on, the duration or length of these fixations, or the time spent fixating on certain areas of the visual display (e.g., Alder, Ford, Causer, & Williams, 2014; Goulet et al., 1989; Milazzo, Farrow, Ruffault, & Fournier, 2015). Several researchers have used gaze behaviour data to infer the location from which information is extracted to facilitate anticipation (e.g., Savelsbergh, Williams, van der Kamp, & Ward, 2002; Singer, Cauraugh, Chen, Steinberg, & Frehlich, 1996; Williams, Ward, Knowles, & Smeeton, 2002). Williams et al. (2002) demonstrated that, in an anticipation task, skilled tennis players spent more time fixating more proximal areas of the opponent's body such as the trunk-hip and head-shoulder region, whereas less-skilled players spent more time fixating more distal regions such as the racket. Similar findings, supportive of occlusion-based research, have been observed in other sports (e.g., cricket [McRobert et al., 2009]; football [Savelsbergh et al., 2002]). However, the extraction of important information cannot be ascertained through the collection of gaze data alone (Hagemann et al., 2010; Mann & Savelsbergh, 2015). For example, although performers may fixate foveal vision on one area of the opponent's body or equipment, they may be simultaneously picking up information from other aspects of the opponent's movements through peripheral vision (e.g., Ripoll, Kerlirzin, Stein, & Reine, 1995; Williams & Elliott, 1999). To determine the important sources of information underpinning expert anticipation, the collection of multiple process-tracing measures or a combination of approaches is preferred (Hagemann et al., 2010; Williams & Davids, 1998).

Pattern perception

When performing in dynamic, time-constrained environments, being able to perceive developing sequences of plays is thought to be an important skill to have, the premise for this being that it may facilitate predictions of what is about to happen (Cañal-Bruland & Williams, 2010; Gorman et al., 2012). Researchers interested in pattern perception in sport have generally employed one of two paradigms, namely, the pattern recall (as outlined earlier) or pattern recognition approach. Originally employed in chess (e.g., Goldin, 1978, 1979; Saariluoma, 1984), the pattern recognition approach entails presenting participants of varying skill levels with a series of patterns, followed by presentation of another series of patterns, some of which have been previously viewed and some of which are novel. During the latter viewing, participants are required to indicate whether they recognise the patterns or not. Akin to the findings of pattern recall studies, experts have demonstrated a performance advantage in recognising patterns in structured action sequences (Goldin, 1978; North, Williams, Hodges, Ward, & Ericsson, 2011; Williams & Davids, 1995). Through manipulations of the information presented in the visual display (Gorman, Abernethy, & Farrow, 2013; Williams, Hodges, North, & Barton, 2006; Williams, North, & Hope, 2012) and collection of gaze data (Gorman, Abernethy, & Farrow, 2015; North, Ward, Hodges, Ericsson, & Williams, 2009; van Maarseveen, Oudejans, Mann, & Savelsbergh, 2016), researchers have made notable attempts to ascertain the specific information sources facilitating effective pattern perception. It appears that information located more centrally in the visual display is of greater importance to these skills than more peripheral features (Gorman et al., 2015; Williams et al., 2012) although the important features are likely to vary from task to task.

Probability assignment

It is thought that the more extensive knowledge base possessed by experts in comparison to less-expert performers, facilitates the assignment of accurate probabilities to potential upcoming event outcomes in domain-specific situations. In comparison to the previously discussed perceptual-cognitive skills, probability assignment has received much less research attention (Loffing & Cañal-Bruland, 2017; Williams & Ward, 2007). Alain and Proteau (1978) provided evidence that the anticipation behaviour of skilled performers is shaped by the probabilities they assign to an upcoming event. The authors originally presented racket sports players (badminton, racketball, squash, and tennis) with rallies they had physically competed in. Through the use of percentage confidence scores, participants were asked to comment on the subjective probabilities they had assigned to the shots hit by the opponent. The authors observed that there was a strong relationship between the subjective probabilities they assigned to the opponent's shot and whether they displayed anticipatory movements (movement made prior to the opponent's racket-ball contact) in the corresponding video footage. More recently, the expert advantage in accurately assigning subjective probabilities to potential event outcomes has been demonstrated in football (Ward & Williams, 2003). Through an alternative approach, it has been demonstrated that providing athletes with objective probabilities associated with potential event outcomes influences behaviour and performance (e.g., Alain & Proteau, 1977; Gray, 2015; Navia, van der Kamp and Ruiz, 2013). With the exception of Ward and Williams (2003), relatively little research has been conducted to compare how expert and less-expert performers assign subjective probabilities to potential event outcomes to inform their anticipation of an upcoming event.

The interaction of perceptual-cognitive skills

Researchers interested in determining the importance of the various perceptual-cognitive skills to expert anticipation have generally examined these skills in isolation of one another (e.g., Müller, Abernethy, Eid, McBean, & Rose, 2010; Ward & Williams, 2003; Williams et al., 2006). While this approach clearly has benefits in that it allows for systematic investigation of specific skills in controlled and reproducible conditions (Williams et al., 2011), the dynamic, complex nature of many sports mean that there are likely to exist very few situations in which performers rely solely on one of the aforementioned perceptual-cognitive skills to anticipate the intentions of an opponent. Additionally, it may result in overreliance on skills that performers would not use to the same extent in a real-world situation, thereby inadvertently hindering the development of our understanding of expert anticipation (Williams & Ericsson, 2005). Williams (2009) suggested that these perceptual-cognitive skills are likely to interact in a dynamic, continuous manner to facilitate expert anticipation.

Roca, Ford, McRobert, and Williams (2013) took an innovative approach to demonstrating the interaction of the different perceptual-cognitive skills during anticipation. Skilled and less-skilled soccer players participated in a representative anticipation task under near and far task constraints (i.e., the ball was either in the defensive or offensive half of the pitch). Gaze data and retrospective verbal reports of thoughts were also collected. First, the authors observed that no one skill appeared to be employed in isolation, with the verbal report data indicating some contribution of postural cue usage, pattern recognition and probability assignment regardless of the task constraints. Second, clear differences in the relative importance of the various perceptual-cognitive skills were observed depending on the task constraints, particularly for skilled participants who were more accurate overall. While skilled participants spent more time fixating the opponent, teammates, and areas of free space in the far compared to the near task and more time on the player in possession in the near compared to the far task, less-skilled participants displayed no such differences. These data were generally supported by the verbal reports. Skilled participants reported more thoughts indicating the use of pattern recognition skills in the far compared to the near task, and greater levels of postural cue utilisation and probability assignment in the near task. Findings illustrate that expert performers develop several domain-specific perceptual-cognitive skills which they employ to varying extents to meet specific task demands.

The role of contextual information

While researchers have invested great time and effort in determining the role of postural information in providing relevant cues to facilitate anticipation, the influence of contextual information and its role as a potential source of relevant cues has received comparatively little research attention (Cañal-Bruland & Mann, 2015). This narrow focus on postural information is at odds with the dynamic conditions expert performers encounter in real-world environments, which are more likely to involve multiple sources of information (Schläppi-Lienhard & Hossner, 2015). Context can be defined as "*the circumstances which form the setting for the event, statement or idea, and in terms of which it can be fully understood*" (Oxford Dictionaries, n.d.). By definition, context therefore appears to be a useful form of information for understanding, and in turn evaluating and predicting the likely outcome of an upcoming event. For example, in medical diagnosis, the provision of contextual information has been shown to increase accuracy and decrease processing time in comparison with when it is not available (e.g., McRobert et al., 2013; Verkoeijen, Rikers, Schmidt, van de Wiel, & Kooman, 2004). Given the particular importance of fast and accurate responses in sports involving extreme time constraints, the limited amount of research examining the contribution of contextual information to anticipation is surprising.

Buckolz, Prapavesis, and Fairs (1988) originally suggested that athletes rely on two broad types of information to anticipate an opponent's intentions; postural and contextual information. While it is acknowledged that pertinent postural cues that facilitate anticipation are only available during the opponent's action execution, some sources of contextual information which may facilitate anticipation are available earlier (i.e., prior to the opponent commencing the action). Moreover these sources of contextual information continue to be available while the opponent executes the action. Although the designs of experimental research studies examining expert anticipation are increasingly incorporating both types of information (e.g., Farrow & Reid, 2012; Loffing, Sölter, Hagemann, & Strauss, 2016; Runswick, Roca, Williams, Bezodis, & North, 2017), traditionally, researchers have controlled the potential effects of contextual information by, for example, presenting participants with isolated actions played by numerous different players from a neutral playing position (e.g., Abernethy & Russell, 1987; Renshaw & Fairweather, 2000; Savelsbergh, van der Kamp, Williams, & Ward, 2005).

Early, field-based research conducted by Abernethy and colleagues (2001) allowed inferences to be made about the type of information skilled performers use to anticipate. The researchers asked skilled and less-skilled squash players to take part in simulated matches. Participants wore liquid crystal occlusion goggles and were informed that, at some stage in the rally, their vision would be occluded. At that point, they should attempt to complete their own shot in response to the shot they anticipated the opponent would hit. When vision was occluded within the last 200 ms leading up to the opponent striking the ball, skilled participants moved more often to the most appropriate corner of the court than less-skilled participants. This finding was interpreted as evidence that the expert advantage in picking up pertinent postural cues to anticipate effectively, as demonstrated in laboratory-based research, translates to field-based settings. Importantly, however, the anticipatory movements of skilled participants continued to be more accurate than chance even when vision was occluded over 580 ms prior to the opponent striking the ball. Given that pertinent postural cues are thought to arise closer to the moment the opponent strikes the ball, the authors suggested that the accurate anticipatory movements of these skilled performers was likely due to their extensive knowledge of event probabilities associated with contextual information such as shot preferences and sequential patterns of play.

Consistent with the findings of Abernethy et al. (2001), Triolet, Benguigui, Le Runigo, & Williams (2013) demonstrated that professional tennis players frequently moved in the direction of the upcoming shot prior to the opponent striking the ball (see Figure 1.2). These anticipatory movements most often occurred when players were placed in unfavourable conditions, such as when the opponent was attacking from inside the court. Such conditions were thought to constrain the players to anticipate the intentions of the opponent in order to avoid negative consequences (i.e., not reaching the ball in time to execute a return shot). While some of these anticipatory movements occurred immediately prior to the opponent's racket-ball contact, a large portion of the movements occurred over 140 ms prior to the ball being struck. The authors inferred that the later occurring anticipatory movements could have been based on postural cues, but that the earlier occurring responses must have been based on contextual information, given that pertinent postural cues would not be available so far in advance of the opponent striking the ball. Collectively, these findings demonstrate that the lack of research into the role of contextual information needs rectifying to provide a more complete and accurate account of expert anticipation. In particular, it appears that expert anticipation is underpinned by an ability to effectively pick up and utilise both postural cues and contextual information arising from an array of potential sources.

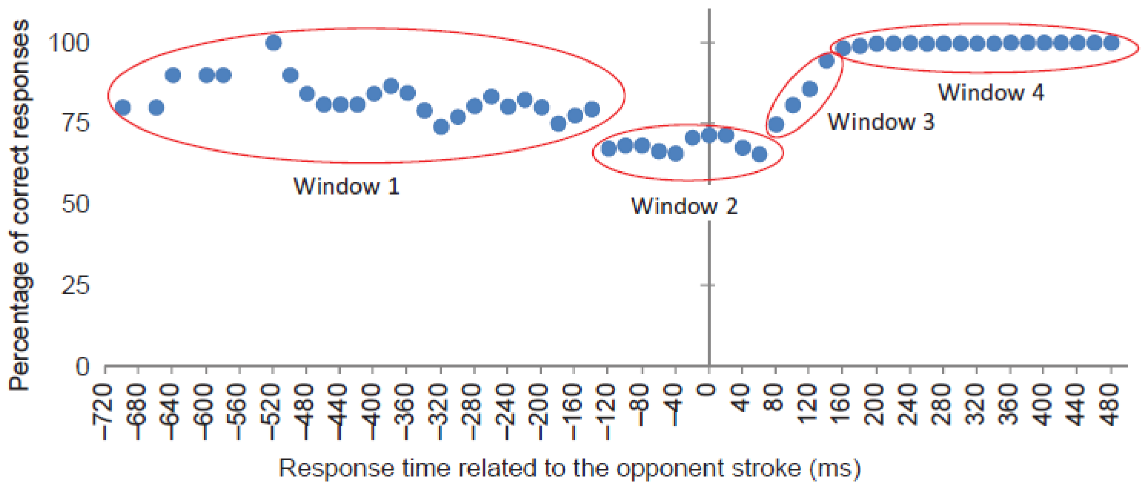


Figure 1.2. Percentage of correct anticipatory movements as a function of response initiation time relative to the opponent's racket-ball contact in professional tennis matches (t = 0)[2].

Cañal-Bruland and Mann (2015) recommended that to develop a fuller understanding of anticipatory behaviour, there is a need for further research which: a) identifies the sources of contextual information that underpin anticipation; b) examines how the different sources of contextual information and postural information influence anticipation; and c) investigates how the circumstances shape the way in which the various sources of information are used or combined. The authors suggested that doing

[2] Reprinted from Journal of Sports Sciences, 31, Triolet, C., Benguigui, N., Le Runigo, C., & Williams, A. M., Quantifying the nature of anticipation in professional tennis, p. 825, 2013.

so would provide strong foundations for the development of an overarching theoretical framework that can explain anticipatory behaviour. While the only research which has provided any indication of the latter recommendation appears to be that conducted by Triolet et al. (2013), several researchers had begun to address the former recommendations, even before the call for more research in the area had been made.

Schläppi-Lienhard and Hossner (2015) conducted interviews with high-skilled volleyball players with the aim of identifying the factors that contribute to anticipation and decision making in defensive situations. Using inductive content analysis, the authors identified several sources of general contextual information that skilled volleyball players use in defensive situations, e.g., the score, preceding events and player positioning. In addition to these general sources of contextual information, skilled volleyball players highlighted the use of opponent-specific contextual information. Opponent specifics differ from general contextual information in that it is individualised contextual information such as action preferences, strengths, weaknesses and characteristic tells that are specific to that opponent alone. While each of these sources of contextual information deserves research attention, this thesis will focus on establishing the importance and impact of general rather than opponent-specific contextual information.

With the exception of Schläppi-Lienhard and Hossner (2015), most researchers interested in determining the sources of contextual information that influence anticipation have manipulated the task environment to compare anticipation performance when this information is available with when it is not. For example, Paull and Glencross (1997) investigated the impact of strategic game information on anticipation in baseball. Skilled and less-skilled baseball batters anticipated the delivery from a pitcher when the pitch count and score information was either available or not. Both groups of participants were able to use this information to decrease errors in ball location prediction and decision time. Findings suggest that strategic game information provides relevant contextual information that batters can use to anticipate more effectively regardless of skill level.

Similarly, Farrow and Reid (2012) examined the influence of game score on anticipation in tennis. Skilled and less-skilled players watched sequences of serves with a score being presented before each serve in the same way as would happen in a tennis match (the participants viewed full service games). The researchers artificially manipulated the outcome of the opponent's serve on the first point in each game, such that this serve was always hit to the same place. Skilled participants detected this pattern to anticipate effectively over 600 ms prior to the ball being struck on that point but the less-skilled participants did not pick up this contextual information. While in the study by Paull and Glencross (1997) generic knowledge about likely outcomes associated with the score is likely to have influenced anticipation (see also Cañal-Bruland, Filius, & Oudejans, 2015), Farrow and Reid's (2012) findings indicate that skilled performers, but not less-skilled, appear to develop expectations through associations between the score and the outcome over short periods of time. In addition to the score, Loffing, Stern, and Hagemann (2015) showed that skilled volleyball players are more strongly influenced by contextual information picked up from the sequence of event outcomes preceding a critical event than less-skilled counterparts.

Attempts have also been made to investigate the impact of specific sources of contextual information on anticipation in representative field-based studies. For example, to determine the effect of tactical initiative on anticipation, Crognier and Féry (2007) manipulated the degree to which participants were allowed to impose their game on the opponent prior to anticipating the outcome of a passing shot. Participants wore liquid crystal occlusion goggles which were activated as the opponent was about to hit the passing shot. Upon occlusion, participants moved as if they were returning the shot.

Anticipation accuracy was highest in the high tactical initiative condition in which the participants were allowed to impose their game on the opponent over a series of shots and lowest in the low tactical initiative condition in which they had no opportunity to do so.

While attempts are therefore being made to address the first recommendation put forward by Cañal-Bruland and Mann (2015), these attempts have largely been isolated attempts in which one potential source of contextual information is artificially manipulated to determine its impact on anticipation. However, in real-world situations multiple sources of contextual information will be available at any given time. Systematic investigation of the impact of the various available sources of contextual information and how they may be combined while anticipating is therefore still needed. Additionally, very little research has been conducted to investigate how contextual information is combined with postural cues during anticipation. Müller and Abernethy (2012) proposed what they referred to as a preliminary model of anticipatory skill in striking sports. In this model, they suggest that contextual information, available prior to the commencement of the opponent's movement pattern, may help prime a skilled athlete's movement response for when more confirmatory postural cues or ball flight information become available. Conversely, less-skilled athletes are thought to rely on late occurring postural cues and ball flight information to inform their judgments. Additionally, they proposed that, in striking sports at least, a progressive switching from the utilisation of contextual to postural information sources is required for effective anticipation. However, this potential interaction between the use of contextual information and postural cues in the lead-up to the critical event is yet to be sufficiently investigated.

A recent exception to this is the research conducted by Loffing and Hagemann (2014). The authors presented skilled and less-skilled tennis players with point-light displays of an opponent hitting down-the-line or cross court shots. The position of the opponent and the moment of occlusion relative to the opponent's racket-ball contact were systematically varied in an attempt to a) examine the influence of contextual information on expectancies of shot outcome and b) investigate the potential interaction between contextual (court positioning) and postural (opponent's movement pattern) information during anticipation. The authors demonstrated that contextual information picked up from an opponent's court positioning influenced expectancies during anticipation and that skilled participants were more strongly influenced by this contextual information than less-skilled participants. Specifically, the further away from the centre line the opponent was positioned, the more likely skilled participants were to anticipate the opponent to direct the shot cross-court. Moreover, the authors observed that the expectancies of skilled participants were most strongly influenced by contextual information early in the development of the opponent's movement pattern. Loffing and Hagemann interpreted this as evidence that skilled performers' more extensive domain-specific knowledge bases allowed them to adjust their expectancies of potential event outcomes based on the contextual information picked up from the opponent's court positioning. The less extensive knowledge bases of less-skilled participants, on the other hand, did not allow them to integrate this information into their judgment of the potential upcoming event to the same extent as the skilled participants.

McRobert, Ward, Eccles, and Williams (2011) investigated whether the perceptual-cognitive processes underpinning anticipation differed depending on the availability of contextual information. Skilled and less-skilled cricket batters were required to anticipate the intentions of bowlers in two conditions in which the level of contextual information available was varied. In the low-context condition, participants viewed footage of bowls from six different bowlers presented in a random order, whereas in a high-context condition participants viewed four different bowlers, with all bowls from each bowler presented in blocks of six, the rationale being that contextual information could be picked up from the action tendencies of the opponent in the high-context condition. The authors observed that both groups performed more effectively in the high- compared to the low-context condition. The skilled participants but not the less-skilled, also adjusted their gaze strategy to extract information from relevant cues more efficiently in the high context condition. Moreover, consistent with Long Term Working Memory (LTWM) theory (Ericsson & Kintsch, 1995), the skilled participants made more evaluation, prediction and deep planning statements than less-skilled participants suggesting that the employment of more elaborate domain-specific memory representations facilitated this adjustment in gaze strategy. Finally, the authors suggested that these representations allowed the skilled participants to use the preceding context to rapidly encode and retrieve task-relevant information during anticipation.

Cognitive processes underpinning expert anticipation and decision making

Ericsson and Kintsch (1995) proposed LTWM theory to account for some processes displayed during expert performance not accounted for by Chase and Simon's theory of expertise (1973). Chase and Simon originally suggested that expertise was characterised by immediate access to relevant knowledge. In recognising structured configurations of chess pieces, these configurations acted as cues to provide access to the best possible moves, which had been stored in Long Term Memory (LTM) from previous experience with that configuration of pieces. The most notable limitation of their theory was the suggestion that expert performers relied on STM for temporary storage of 'chunks' of information. Subsequent to the seminal research of Chase and Simon (1973), expert performers were shown to not only be able to maintain high levels of recall of domain-specific information despite interpolation in a recall task (Charness, 1976), but that they could rapidly encode large amounts of information (Frey & Adesman, 1976), and rapidly retrieve encoded information from LTM (Anderson, 1990). Ericsson and Smith (1991) concluded that the mechanism put forward by Chase and Simon (1973) was overly restrictive as it proposed that the processing demands of working memory were constrained to work within the limits of STM.

In light of these developments, Ericsson and Kintsch (1995) proposed that expert performers develop skills which allow them to circumvent or extend the limited capacity of working memory based on STM. Through experience and practice (Ericsson et al., 1993), expert performers acquire retrieval structures that facilitate encoding of domain-specific information with retrieval cues, which are related to prior knowledge and facilitate the retrieval of large amounts of relevant information from LTM. This process becomes more efficient with deliberate practice in the domain (Ericsson et al., 1993), in that the time taken to encode and retrieve domain-specific information reduces to a point comparable with that which would be expected if the information was being retrieved from STM. In addition to proposing an explanation of how expert performers circumvent the limitations of STM in pattern recall or other memory tasks, LTWM theory (Ericsson & Kintsch, 1995) proposes an insight into the cognitive mechanisms underlying expert performance in complex tasks requiring efficient anticipation and decision making skills. Specifically, an important feature of the retrieval structure is that upon activation during encoding, it facilitates prediction of future retrieval demands, and the generation and evaluation of multiple relevant options, which ultimately enhances decision quality (Ericsson, Patel, & Kintsch, 2000).

Indicative of their more elaborate domain-specific memory representations, in representative tasks, expert performers generally report engagement in more evaluation and forward planning than less-expert counterparts (Ericsson et al., 2000), rather than the mere monitoring of immediately available information. Through the use of think-aloud verbal report protocols (Ericsson & Simon, 1993), researchers have demonstrated that the superior performance of experts is underpinned by these processes in sport (e.g., McRobert et al., 2011; Roca, Ford, McRobert, & Williams, 2011), law enforcement (Ward et al., 2011), and medical diagnosis (McRobert et al., 2013). More recently, option generation paradigms have been employed during anticipation and decision making tasks to demonstrate that, expert performance is associated with the generation of not only the best or most likely option but also potential relevant alternatives (Belling, Suss, & Ward, 2015a, Suss & Ward, 2012; Ward, Ericsson, & Williams, 2013). Collectively, these findings are consistent with the notion that the retrieval structures developed by expert performers do not prescribe a set response but rather they allow access to potential relevant alternatives, facilitating higher quality decisions (Ericsson et al., 2000).

Alternative models of expert decision making propose that increased levels of expertise are associated with lower levels of cognitive evaluation. As part of his seminal research on expertise in chess, de Groot (1965) highlighted that the superior performance of expert chess players was often characterised by quick recognition of the next best move, rather than generation and evaluation of potential alternative moves. More recently, Klein and colleagues proposed the Recognition Primed Decision (RPD) model (e.g., Klein, 1993; Klein, Calderwood, & Clinton-Cirocco, 1986). The RPD model suggests that, through repeated exposure to a particular situation, expert performers develop associations between the information available within the environment and the optimal response. When similar information is encountered in subsequent performance, the information is recognised and matched to an appropriate response. Alternative responses are only generated if, having mentally simulated that response, it is deemed inappropriate. Based on similar principles as the RPD model, Johnson and Raab (2003) later proposed the Take The First (TTF) heuristic. In contrast to the evaluation and forward planning LTWM theory (Ericsson & Kintsch, 1995) associates with expert performance, the TTF heuristic model recommends that expert performers should take the first option that comes to mind, as this will be the highest quality option generated. Raab and colleagues (e.g., Johnson & Raab, 2003; Raab & Johnson, 2007; Laborde & Raab, 2013) have provided support for the TTF heuristic model in a series of experiments on expert decision making in handball. At this point however, our knowledge of the cognitive processes underlying the use of contextual information during expert anticipation, as well as how this information is combined with postural information, is limited (for exceptions see Loffing & Hagemann, 2014; McRobert et al., 2011; Milazzo et al., 2015).

Aims of the Thesis

The overall aim of the current thesis is to examine the role of contextual information in expert anticipation, with tennis being used as a vehicle to explore the issue. To achieve this aim, comparisons will be made between skilled and less-skilled tennis players over the course of five studies. The extent to which contextual information can be used to anticipate the intentions of an opponent relative to when pertinent postural cues are also available will be investigated, the specific sources of contextual information contributing to anticipation explored and the mechanisms underpinning anticipation under different informational constraints examined.

Thus far, researchers have only been able to infer, based on the timing of anticipatory movements, that expert performers can anticipate effectively based on contextual information picked up in advance of pertinent postural cues becoming available (Abernethy et al., 2001; Triolet et al., 2013) and little is known about how they may do so. In Chapter 2 (Studies 1 and 2), an attempt is made to determine the extent to which tennis players can anticipate the outcome of an opponent's shot when presented with contextual information alone, compared with when pertinent postural cues are also available for processing, and to investigate the processes underpinning skilled anticipation when constrained to anticipate based on contextual information alone. In Study 1, skilled and less-skilled tennis players will be presented with open-play rallies from real tennis matches in two conditions; a video condition in which all information that would normally be available to players is available (i.e., both contextual and postural information), and an animated condition which has been edited to omit the bodies and rackets of the players such that participants are constrained to anticipate based on contextual information alone (e.g., player positioning, shot sequencing). It is expected that both contextual and postural information will contribute to accurate anticipation and that skilled participants will be able to use both types of information more effectively than less-skilled counterparts. In Study 2, gaze data and verbal reports of thoughts will be collected to examine the perceptual-cognitive processes underpinning anticipation when constrained to anticipate based on contextual information alone. It is expected that skilled participants will display different gaze behaviour (Mann et al., 2007) to less-skilled participants as well as thought processes supportive of Long Term Working Memory theory (Ericsson & Kintsch, 1995) as an explanation of expert anticipation.

In light of the first recommendation made by Cañal-Bruland and Mann (2015), in Chapter 3 (Studies 3 and 4), an attempt is made to identify the specific sources of contextual information which facilitate anticipation. Skilled and less-skilled tennis players will be presented with animated footage from which they will be constrained to anticipate based on contextual information alone. The test stimuli viewed by participants will be manipulated to examine the extent to which various sources of contextual information (shot sequencing, ball and player motion and positioning) facilitate anticipation. In Study 3, participants will anticipate the outcome of an opponent's shot in three conditions in which the number of shots in the sequence preceding the final occluded shot is systematically varied. It is expected that participants will be more accurate when the preceding shot sequence is presented than when it is not and that skilled participants will use this information more effectively than less-skilled counterparts. In Study 4, participants will be presented with sequences of a fixed length which depict only the ball, the players, or both the ball and the players, in dynamic or still form. Overall, decrements or increases in performance levels when a particular source of information is omitted or made available in comparison to a control condition will provide an indication of the extent to which that source of contextual information facilitates anticipation.

While several researchers have investigated the cognitive processes underpinning expert anticipation, how expert performers generate options prior to selecting the option considered most likely to occur has received surprising little research attention, particularly considering the importance of this process in the natural ecology (Klein, 1993). In Chapter 4 (Study 5), the option generation strategies of skilled and less-skilled tennis players when anticipating the outcome of an opponent's shot will be investigated. As in Study 1, participants will view animations of rallies in which they are constrained to anticipate based on contextual information alone or videos in which pertinent postural cues are also available for processing. It is expected that the option generation strategies employed by expert performers will be consistent with LTWM theory (Ericsson & Kintsch, 1995), in that the generation of relevant alternative options in addition to the most likely outcome will result in more accurate anticipation. The use of an option generation paradigm in this study will further provide an initial insight into how expert performers integrate contextual and postural information to facilitate anticipation (Cañal-Bruland & Mann, 2015).

Finally, in Chapter 5, an epilogue is presented which is used to illustrate and bring together the main findings of the thesis. It will further be used to demonstrate how the thesis has contributed to the development of knowledge, both theoretically and from an applied perspective, as well as to identify limitations of the research programme. Moreover, future research directions will be outlined, with a clear focus on how researchers can extend this and other emerging research to develop a fuller understanding of this relatively nascent research area.

Methods

A range of methods will be employed in the forthcoming experimental chapters to address the specific aims of the thesis, some of which are commonly employed by researchers and some more novel. To investigate the impact and importance of contextual information during skilled anticipation, throughout the thesis, participants will be presented with novel test stimuli. Player movement and ball trajectory data from real tennis matches will be used to create animations that simulate rallies played between two players while omitting postural information and the rackets of the players from the visual display. The presentation of test stimuli that omits postural information from the display will thereby constrain participants to anticipate based on contextual information alone. A similar approach has been taken to investigate how biological motion information can be used to anticipate an opponent's intentions (e.g., Abernethy et al., 2008; Huys et al., 2009; Ward, Williams, & Bennett, 2002).

In Studies 2 and 5, the processes and mechanisms underpinning skilled anticipation will be examined. Gaze behaviour and verbal report data will be collected in Study 2 to examine the perceptual-cognitive processes underpinning skilled anticipation, specifically, when constrained to anticipate based on contextual information alone. While gaze behaviour data will provide an indication of the information source being fixated on, verbal reports will provide an indication of how participants cognitively process this information prior to making a response. These methods have frequently been employed by researchers interested in further understanding the perceptual-cognitive processes underpinning skilled anticipation (e.g., McRobert et al., 2009; North et al., 2011; Roca et al., 2011). Conversely, the option generation paradigm, as employed in Study 5 has been employed much less frequently. Option generation tasks allow researchers to examine the cognitive strategies that support skilled anticipation and decision making, however the majority of researchers employing this approach have examined decision making rather than anticipation (for exceptions see Belling et al., 2015a; Belling, Suss, & Ward, 2015b). In option generation tasks, rather than being required to choose between a set number of options, participants indicate the options they generated and considered prior to anticipating the action outcome, such as would be necessary in the natural ecology (Klein, 1993). This approach therefore facilitates further examination of the cognitive strategies that support anticipation in real-world situations.

In line with Ericsson and Smith's (1991) Expert Performance Approach, researchers now commonly attempt to capture expert performance in laboratory-based settings using life-size video simulations (e.g., McRobert et al., 2009; Roca et al., 2011; Williams et al., 2002) and movement-based responses (e.g., McRobert et al., 2009; Roca et al., 2013). The use of large screens onto which test stimuli are projected rather than smaller screen sizes is based on the assumption that this creates a more realistic environment for the participant (Williams & Davids, 1998). Similarly, in comparison to pen and paper responses that were used in earlier research (e.g., Abernethy & Russell, 1987; Buckolz et al., 1988; Jones & Miles, 1978), requiring participants to move while responding to test stimuli is proposed to increase the fidelity of the task (Roca et al., 2013). Where feasible, an attempt is made to maintain a realistic task environment throughout the thesis, while nevertheless maintaining acceptable levels of internal validity and experimental control.

Chapter 2

Contextual information and perceptual-cognitive expertise in a dynamic, temporally-constrained task

Abstract

Skilled performers extract and process postural information from an opponent during anticipation more effectively than their less-skilled counterparts. In contrast, the role and importance of contextual information in anticipation has received only minimal attention. We evaluate the importance of contextual information in anticipation and examine the underlying perceptual-cognitive processes. We present skilled and less-skilled tennis players with video or animated footage of the same rallies. In the animated condition, sequences were created using player movement and ball trajectory data, and postural information from the players was removed, constraining participants to anticipate based on contextual information alone. Participants anticipated ball bounce location of the opponent's final occluded shot. The two groups were more accurate than chance in both display conditions with skilled being more accurate than less-skilled participants (Study 1). When anticipating based on contextual information alone, skilled participants employed different gaze behaviours to less-skilled counterparts and provided verbal reports of thoughts which were indicative of more thorough evaluation of contextual information (Study 2). Findings highlight the importance of both postural and contextual information in anticipation and indicate that perceptual-cognitive expertise is underpinned by processes that facilitate more effective processing of contextual information, in the absence of pertinent postural cues.

Introduction

Researchers interested in anticipation in real-world tasks often use tennis as a vehicle to explore the underlying mechanisms due to the extreme time constraints involved. Ball speeds can reach over 200 $km \cdot h^{-1}$ (Gillet, Leroy, Thouvarecq, & Stein, 2009). The time it takes for the ball to travel from one player to the other can be as little as 500 ms, meaning it is sometimes impossible for players to respond quickly enough to return the opponent's shot based on ball flight information alone (Abernethy & Wollstein, 1989). The extreme time constraints evident in fast ball sports (Gray, 2002a), coupled with the fact that an opponent can potentially disguise his/her intentions or present deceptive information (Jackson, Warren, & Abernethy, 2006; Kunde, Skirde, & Weigelt, 2011; Rowe, Horswill, Kronvall-Parkinson, Poulter, & McKenna, 2009), suggest that the contextual information which is available prior to pertinent postural cues becoming available could be both valuable and necessary when making anticipation judgments.

The majority of researchers focusing on anticipation, particularly in racket-sports, have focused on how performers use advance postural cues to inform their judgments (for reviews see Crognier & Féry, 2007; Mann et al., 2007). However, recent calls have been made for more research investigating the role of contextual information in anticipation (Cañal-Bruland & Mann, 2015, Triolet et al., 2013). It is well established that skilled performers are better able to extract and process postural information from an opponent to more accurately (e.g., Abernethy & Russell, 1987; Jones & Miles, 1978) and more quickly (e.g., Ward et al., 2002; Williams et al., 2002) anticipate the outcome of an upcoming event than their less-skilled counterparts. To rigorously examine how skilled performers more effectively utilise postural information, researchers have traditionally employed quasi-experimental cross-sectional designs (comparing skilled and less-skilled performers) in which participants anticipate the outcome of an event based solely on the postural information emanating from an opponent (e.g., Goulet et al., 1989; Jackson & Mogan, 2007). In such experimental set-ups, contextual information built up prior to the event is usually omitted, such that the opponent's positioning is limited to a single location of the playing area throughout trials.

However, published research suggests that skilled performers can effectively anticipate the outcome of an upcoming event based on contextual information picked up in advance of pertinent postural cues becoming available (Abernethy et al., 2001; Triolet et al., 2013). Moreover, contextual information can be used by skilled performers to anticipate more effectively than when it is not available, (e.g., Crognier & Féry, 2005, Farrow & Reid, 2012). Several researchers (e.g., McRobert et al., 2009; Roca et al., 2011) have explained the processes underpinning skilled anticipation using Long-Term Working Memory (LTWM) theory (Ericsson & Kintsch, 1995). Nevertheless, both our understanding of the extent to which performers can use contextual information to anticipate effectively in advance of pertinent postural cues becoming available, and the perceptual-cognitive processes underpinning such judgments is limited.

Triolet et al. (2013) quantified anticipation behaviour in professional tennis matches. A key finding of this research was that while some anticipation behaviour was found to occur around the time of the opponent's racket-ball contact, a large portion of effective anticipation behaviour occurred over 140 ms prior to the opponent striking the ball. Moreover, a large portion of this early anticipation behaviour occurred when the receiving player was under 'unfavourable' conditions, that is, under extreme time constraints. If a visual-motor delay of approximately 200 ms (Hick, 1952) is assumed, players must have been anticipating based on information arising at least 340 ms prior to the opponent's racket-ball contact. Triolet and colleagues concluded that these highly skilled performers were using contextual information to anticipate in advance of pertinent postural cues becoming available. These findings indicate that contextual information may play an important role in skilled anticipation, particularly in fast ball sports such as tennis, in which players often perform under extreme time constraints, and it is not viable to wait for pertinent postural cues to become available.

In a related study Abernethy et al. (2001) demonstrated that skilled squash players are able to anticipate shot direction and depth at levels significantly greater than chance over 580 ms before the opponent's racket-ball contact. They concluded that the skilled squash players' performance advantage was due to their superior attunement to information picked up from within their opponent's pattern of play (e.g., accurate knowledge of event probabilities, shot sequencing information). Similarly, Loffing and Hagemann (2014) demonstrated that the positioning of the opponent relative to court markings provides contextual information about the direction of the opponent's shot, and that skilled players rely more on this positional information in advance of pertinent postural cues becoming available.

This body of research indicates that skilled performers can use early advance information to anticipate effectively (Abernethy et al., 2001; Triolet et al., 2013) and that they do so when placed under extreme time constraints such as when the opponent is attacking or when the distance between the two players is reduced (Triolet et al., 2013). It is not yet clear though, whether this advance information is picked up from very early occurring postural cues or from contextual information, because postural information has always been readily available to participants. While postural information from the opponent will always be available in competition as the opponent's body is always visible, the moment at which this information can reliably inform skilled performers' anticipation judgments varies across sports and situations (Abernethy et al., 2001). It is therefore difficult to infer the type of information performers are using based solely on how far in advance of the event they are acting on an anticipation judgment.

Context can be defined as *“the circumstances that form the setting for an event, statement, or idea, and in terms of which it can be fully understood”* (Oxford Dictionaries, n.d.). Contextual information can come in many different forms, such as knowledge of an opponent’s strengths/weaknesses, players’ positioning relative to one another and climatic conditions (Buckolz et al., 1988). The positive effect of providing contextual information to participants in addition to postural information has been demonstrated in several sports (for a review, see Cañal-Bruland & Mann, 2015). Researchers have demonstrated higher levels of anticipation performance when participants are provided with contextual information in the form of scores and number of balls and strikes in baseball (Paull & Glencross, 1997), increased exposure to the bowler in cricket (McRobert et al., 2011) and knowledge of the opponent’s action preferences in soccer (Navia et al., 2013). In tennis, Crognier and Féry (2005) demonstrated that players anticipated more accurately in a high context, which they termed high tactical initiative, condition in which they were allowed to impose their game on the opponent over a series of shots, compared to when they were not allowed to do so and no shots were played prior to the opponent’s occluded passing shot. Farrow and Reid (2012) demonstrated that skilled tennis players can use knowledge of the opponent’s serving tendencies to increase the speed of their anticipation judgments.

Conversely, researchers have found that presenting performers with contextual information can also yield a decrease in performance. In a simulated baseball batting task, Gray (2002a, 2002b) demonstrated that while contextual information picked up from the preceding sequence of pitches and pitch count influences batting accuracy, this information negatively affected performance when incongruence existed between the actual and expected pitch. Mann, Schaefers, and Cañal-Bruland (2014) and Loffing et al. (2015) have produced supportive findings of such an effect in handball and volleyball anticipation judgment tasks. Collectively, these findings suggest that while contextual information is often beneficial to performance, situations exist when attending to contextual information can be misleading and the use of reliable postural information may be more favourable. However, under extreme time constraints, it is not always feasible for performers to wait for such information to act.

As opposed to manipulating contextual information when postural information is readily available, we provide a novel contribution by comparing anticipation response accuracy either in the presence or absence of postural information at the same moment so that conclusions can be drawn about the extent to which performers can use contextual information to anticipate effectively. We consider contextual information to constitute the circumstances which form the setting for the event; circumstances which in advance, or in the absence of pertinent postural cues would necessarily be relied upon to make anticipation judgments. Therefore, contextual information in our anticipation task refers to the sequential relative movements of the players and the ball flight in the lead up to the critical event (the to-be-anticipated shot played by the opponent), and the players' resultant positioning at the moment of the event. In contrast, postural information refers to the bodily movements of the players and their resultant racket movements. In Study 1, we investigate the extent to which tennis players can anticipate based on contextual information alone compared with performance based on this information as well as postural information. Moreover, because skilled performers have previously been shown to anticipate more effectively than their less-skilled counterparts in advance of pertinent postural cues becoming available (Abernethy et al., 2001), in Study 2 we aim to determine *how* they do so, by tracing the perceptual-cognitive processes underlying judgments when constrained to anticipate based on contextual information alone.

Process-tracing measures such as the recording of gaze behaviour, collection of verbal reports of thoughts, and manipulations to representative tasks are often used to identify the mechanisms underpinning skilled performance (e.g., Afonso, Garganta, McRobert, Williams, & Mesquita, 2012; Catteeuw, Gilis, Wagemans, & Helsen, 2010; Ward et al., 2013). A comprehensive understanding of the perceptual-cognitive processes underlying anticipation provides an insight into how skilled performers process information more effectively than their less-skilled counterparts. This information can then be used to guide practice organisation for training and development purposes (Williams et al., 2011).

Ericsson and Kintsch's (1995) Long Term Working Memory (LTWM) theory states that as a result of extended experience and practice, skilled performers have developed complex domain-specific memory representations. When they encounter information during practice or competition, they can accurately encode and store this information in LTM. The information is associated with a retrieval cue in STM, meaning that when similar situations are subsequently encountered, skilled performers can rapidly access the associated information stored in LTM through these retrieval cues. Skilled performers can therefore access information about previous outcomes in similar situations to guide their anticipation judgments. During practice skilled performers are exposed to a diversity of events and situations (e.g., the opponent in a tennis practice match hitting an attacking forehand from inside the court), and are provided with the opportunity to respond to these events (e.g., by anticipating the depth and direction of the opponent's shot and attempting to return the shot). This gives the skilled performer the opportunity to encode information from these situations, associate this encoded information with a retrieval cue, and store the information in LTM. When skilled performers encounter a similar situation in subsequent performance, the presented information is associated with a retrieval cue, allowing for the rapid retrieval of relevant information about that situation and potentially the previous outcomes of such a situation from LTM. Less-skilled performers, on the other hand, have not developed such elaborate memory representations due to their relative lack of experience. Several researchers have provided support for LTWM theory (Ericsson & Kintsch, 1995) in domain-specific anticipation tasks (e.g., North et al., 2011; Roca et al., 2011; Ward et al., 2013), citing skilled performers more elaborate domain-specific memory representations as the reason for differences in performance between skill groups.

Verbal reports of thoughts recorded during (concurrently) or immediately following (retrospectively) an anticipation task provide an insight into performers' task-specific knowledge and cognitive processes when carrying out a task (Anderson, 1987). Ericsson and Simon's (1993) protocol analysis method has frequently been used to categorise the cognitive processes underlying skilled performance. In representative domain-specific anticipation tasks, skilled performers have been shown to verbalise more thoughts relating to evaluation of the event and prediction of potential future outcomes than their less-skilled counterparts (e.g., McRobert et al., 2011; North et al., 2011; Roca et al., 2011). The higher number of evaluation and prediction statements made by skilled performers when reporting their thoughts have been interpreted as being supportive of LTWM theory (Ericsson & Kintsch, 1995).

It has been suggested that skilled performers' more elaborate memory representations in domain-specific situations direct their gaze to the more pertinent information present in the environment (Williams & Elliott, 1999). Increasingly, researchers have collected data for perceptual and cognitive process measures in the same study so as to establish much more fully the processes contributing to performance differences (Afonso & Mesquita, 2013; McRobert et al., 2011). While the visual search strategy employed is dependent on the task-constraints (Roca et al., 2013; Williams, Janelle, & Davids, 2004), skilled performers have usually been shown to employ different strategies to those of their less-skilled counterparts (for a review, see Mann et al., 2007).

In a representative cricket task, McRobert et al. (2011) varied the number of times in a row participants viewed a particular bowler to compare the perceptual-cognitive processes employed by batters in low- and high-context conditions. Verbal report data revealed that the batters made more evaluation and deep planning statements when contextual information was available about the bowler being viewed and skilled batters made more evaluations, predictions and deep planning statements in both conditions, which the authors suggested contributed to their superior performance on the task. Gaze data indicated that skilled batters adapted their visual search strategies in the high-context condition to more efficiently extract pertinent information from the visual display than in the low-context condition. These data were interpreted to mean that in high-context conditions, skilled batters are able to use contextual information (in this case picked up from an opponent's prior actions), to rapidly encode and retrieve task-relevant information stored in LTM. However, thus far, no researchers have investigated whether skilled performers use similar processes when presented with contextual information alone, as would be the case when performers are under extreme time constraints and pertinent postural cues picked up from the opponent are therefore not available.

Although the aforementioned studies provide us with valuable information about perceptual-cognitive expertise, to our knowledge postural information and/or incoming ball flight information has always been readily available to the participant when carrying out the task, making it possible for participants to base their judgments solely on the availability of such information. This approach may be somewhat misleading when we consider the multidimensional nature of anticipation (i.e., the potential importance and contributions of various sources of information and constraints placed on performers in the anticipation process, Müller & Abernethy, 2012; Roca et al., 2013). Triolet et al. (2013) reported that skilled performers often act in advance of pertinent postural cues becoming available due to the extreme time constraints involved. As such, it is important to determine how skilled performers process the information that would necessarily be relied upon when pertinent postural cues are not available. In the current paper, we first investigate the extent to which skilled and less-skilled tennis players can use contextual information to anticipate. Second, we examine the perceptual-cognitive processes underlying anticipation judgments based on contextual information alone.

Study 1

We used a laboratory-based simulation of an anticipation task to compare the performance of skilled and less-skilled tennis players when viewing test stimuli which either omitted postural information, so as to present only the sequential relative movements of the players and the ball flight in the lead up to the opponent's shot (animated condition), or which presented this contextual information as well as postural information (video condition). First, we examined whether the presentation of contextual information alone allows for effective anticipation or if postural information is necessary to anticipate effectively. Based on the findings of Abernethy et al. (2001) and Triolet et al. (2013) we hypothesised that all tennis players would be able to anticipate at levels significantly greater than chance in both video and animated conditions. Second, we determined the extent to which providing postural information in addition to contextual information affects anticipation accuracy. We hypothesised that participants would be more accurate in the video condition than in the animated condition due to the availability of pertinent postural cues (Müller & Abernethy, 2012). We further hypothesised that the increase in accuracy from animated to video condition would be greater in the skilled than the less-skilled group due to the skilled group's greater ability to pick up and utilise pertinent postural cues from an opponent (Mann et al., 2007). Third, we investigated whether skilled participants would be more accurate than their less-skilled counterparts when presented with contextual information alone, as well as when presented with both contextual and postural information. We hypothesised that skilled participants would be more accurate than less-skilled participants in both the video condition in which postural information was readily available (Mann et al., 2007) and in the animated condition in which contextual information would be used to inform judgments (Abernethy et al., 2001; Loffing & Hagemann, 2014).

Methods

Participants

Altogether, 16 skilled (M_{age} = 24.0 years, *SD* = 5.6) and 20 less-skilled (M_{age} = 24.1 years, *SD* = 4.7) male tennis players participated. Skilled participants had a mean of 17.8 (*SD* = 5.5) years of tennis playing experience, 12 of whom held an Association of Tennis Professionals (ATP) singles ranking (mean career high ranking of 671 [*SD* = 418] in the world). Less-skilled participants had a mean of 7.0 (*SD* = 4.8) years of tennis playing experience. Skilled and less-skilled participants had played a mean of 13.3 (*SD* = 3.6) and 1.4 (*SD* = .6) hours tennis per week throughout their career respectively. Skilled participants had competed in 19.1 (*SD* = 7.3) tournaments per year, whereas less-skilled participants had not competed in competitive tennis tournaments outside of internal staff box leagues or schools tennis. Two participants in each group were left-handed with respect to the hand they normally use to play tennis, whereas all other participants were right-handed. All participants reported normal or corrected vision and those with corrected vision wore contact lenses or glasses. Participants gave their written informed consent prior to taking part and were informed that they could withdraw at any time without penalty. The work was carried out according to the ethical guidelines of the lead university.

Test Stimuli

Footage of professional men's tennis matches was collected at the AEGON Championships (2013) at The Queen's Club, London from a height of 1.9 m above the ground, 6.4 m behind the centre of the court's baseline, using a 30 Hz wide angle HD video camera (Contour Roam, Contour Inc., Seattle, USA). The camera was positioned such that the two players' movements and ball flight were captured with the opponent whose shot the participant was anticipating in the test stimuli always being the player positioned on the far side of the court. A total of 11 matches were recorded from various rounds of the tournament, which provided footage of 15 different players, all of whom were right-handed.

Test stimuli were created in two display conditions, namely video and animated (see Figure 2.1). Animated trials were created using player movement and ball trajectory information of the same points used in the video condition. A 10-camera system positioned around the court during matches tracked the ball's trajectory and players' movements throughout points (Hawk-Eye Innovations Ltd., Basingstoke, England). Ball flight information was in the form of trajectory data (x, y, z coordinates as a function of time) while player movement data were in the form of x, y coordinates. The data from selected points were input into the LTA rendering engine (Julien Pansiot, London, UK, 2013) through which animated videos of the data were generated for use with VLC media player (VideoLAN, Paris, France). The principal difference between the two display conditions was that postural information of the players was not visible in the animated condition. In place of seeing the players and their rackets, participants saw a blue and a red cylinder representing each player and the ball as a yellow dot, while rackets were not visible. In both display conditions trials were occluded at the opponent's racket-ball contact using Pinnacle Studio 15 editing software (Pinnacle, Ottawa, Canada).

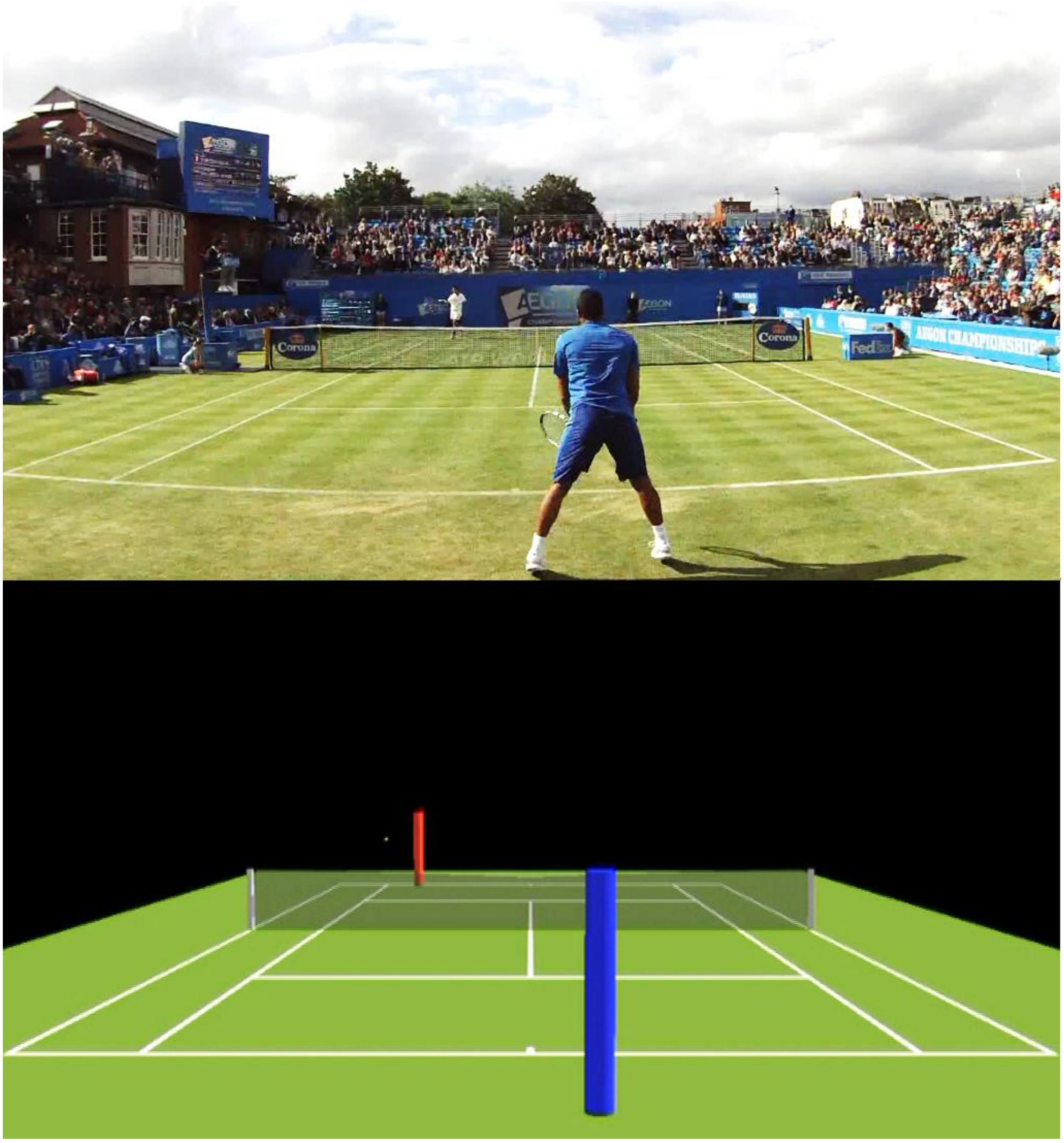


Figure 2.1. Video (top) and animated (bottom) display conditions.

Experimental trials were made up of footage from 90 rallies, with the final occluded shot played by the opponent to one of four areas on the court. Those shots the opponent hit on which the first bounce landed before or after the service line were classified as short and deep respectively, while those shots which landed to the right or left of the centre line were classified as such. The number of shots played to the four areas of the court on the final occluded shot was: deep-left (32); deep-right (32); short-left (13); and short-right (13). The order of the bounce location of the opponent's final occluded shot was randomised across trials and conditions. The number of shots played prior to the opponent's occluded shot in trials was between 2 and 12. Trials were between 5 and 18 seconds long, beginning 3 seconds prior to racket-ball contact of the serve at the beginning of the point. An inter-trial interval of 6 seconds was employed.

Three Lawn Tennis Association (LTA) tennis coaches, all of whom were coaching national and/or international players on a full-time basis, recommended presenting situations in which the receiving player (on the near side of the screen) was placed under extreme time constraints as test stimuli. The rationale for doing so was that in a match situation such extreme time constraints are likely to force the player to anticipate the outcome of the opponent's shot early, in order to return it successfully, as it may not be feasible to wait for pertinent postural cues or ball flight information to become available. In support of this practical recommendation, Triolet et al. (2013) reported that in professional men's tennis matches, anticipation behaviour is more prevalent when the balance of power is unfavourable for the receiving player, and when the spatiotemporal constraints are therefore more extreme. The selected situations in which trials were occluded at the opponent's racket-ball contact were made up of attacking forehand and backhand drives, passing shots, volleys, and drop-shots, all of which meant that the receiving player was under extreme time constraints, the balance of power was unfavourable for him, or both. A total of 150 points (150 videos and the corresponding 150 data sets to be used to render animations) were originally selected, with points being omitted if the footage was of low quality, due to poor weather and lighting, or if the data used to render the animations contained errors, such as gaps in ball flight information. We thereby reduced the number of trials from 150 to 90, which were viewed in both video and animated display conditions (90 videos and 90 animated trials).

Materials, Apparatus, and Set-Up

Footage was projected on to a 4.1 × 2.3 m white projection screen (AV Stumpfl, Wallern, Austria) using a NEC PE401H HD projector (NEC, Tokyo, Japan). Participants began each trial standing 5 m from the screen holding a racket in their hands as if ready to play a point. Testing was conducted in a large enough room for participants to be able to move around and swing the racket freely. The screen further allowed for recreation of a realistic vertical visual angle of 2.5° - 3.7° subtended by the opposing player. A similar visual angle has been used in other studies of this nature, (e.g., Loffing, Wilkes, & Hagemann, 2011).

Procedure

Participants viewed 16 familiarisation and 180 experimental trials, half of which were shown in the video condition and half in the animated display condition. The rallies used in familiarisation trials were different to those used in experimental trials. Participants viewed trials in blocks of 30 with a one minute break between each of the blocks except between the third and fourth blocks for which they had a three minute break (merely to have a longer break half-way through the protocol). The order of display conditions was counterbalanced across participants: half the participants in each group viewed a block of 30 animated trials followed by five further blocks of 30 clips that alternated between video and animated trials. The remaining participants viewed a block of 30 normal trials followed by five further blocks of 30 trials that alternated between animated and video. Prior to commencing the protocol, participants were informed that each of the occluded shots played by the opponent landed in the legal playing area, in one of the four sections of the court (deep-left, deep-right, short-left, short-right). During trials participants were allowed to move freely. Upon occlusion at the opponent's racket-ball contact, the screen would go black and participants verbally indicated depth and direction of the ball bounce location, while swinging the racket and moving as if to return the shot. The verbal response was recorded. Participants did not receive feedback after any trials.

Data Analysis

Response accuracy was reported as the percentage of correct anticipation judgments relative to the actual final ball bounce location of the occluded shots. To determine whether participants could anticipate more effectively than chance, one-sample *t*-tests were carried out to compare depth, direction, and combined response accuracy of the two groups with response accuracy that would be expected due to chance. To examine the extent to which skilled and less-skilled participants can use contextual information alone and both contextual and postural information to inform their judgments, a 2 × 2 (Display [video, animated] × Group [skilled, less-skilled]) multi-factorial MANOVA with repeated measures was conducted for response accuracy, with the percentage of correct depth, direction, and combined judgments serving as the dependent variables. Wilks' Lambda values are reported for the multivariate output while the Greenhouse-Geisser correction was applied in the case of violations of Mauchly's test of sphericity. Partial eta squared (η_p^2) values are reported throughout for effect size of main effects. The alpha level of statistical significance was set at .05 with the sequential Bonferroni correction applied to control for family-wise error where multiple *t*-test comparisons were conducted. Finally, pairwise comparisons were carried out in the case of significant interactions while Cohen's *d* is reported for effect size of these comparisons.

Results and Discussion

Response Accuracy Data

Mean scores and standard errors of response accuracy for the skilled and less-skilled groups are presented in Figure 2.2. First, we hypothesised that participants would be more accurate than chance in both the video and animated conditions. As expected, both groups' response accuracy scores were significantly higher than would be expected due to chance in both video and animated display conditions when making depth, direction, and combined anticipation judgments (all $p < .01$). This primary finding demonstrates that tennis players can use contextual information to make more accurate anticipation judgments than would be expected due to chance when no postural information is available from the visual display to inform their judgments. This finding supports previous research showing that contextual information plays an important role in anticipation (Abernethy et al., 2001; Triolet et al., 2013). Moreover, data extend previous work by confirming that anticipation judgments may be made more accurately than would be expected due to chance in the absence of pertinent postural cues. The high mean scores for combined judgments of both skilled and less-skilled groups in the animated condition (49.10% and 44.00% respectively) when compared to chance level (25.00%) indicate that not only is this a useful source of information, but it is a source that both skilled and less-skilled performers are able to exploit. These findings resemble those in studies in which participants have been presented with point-light displays of the opponent alone. In that body of research, performers were shown to be able to use minimal biological motion information to anticipate at levels significantly greater than chance (e.g., Abernethy et al., 2008; Abernethy & Zawi, 2007; Ward, et al., 2002). In the present study, the sequential relative movement of the players and the ball flight provided a sufficiently informative basis from which participants were able to anticipate the outcome at better than chance levels.

We hypothesised that participants would be more accurate in the video than in the animated condition. Analysis of the response accuracy data was consistent with this hypothesis, revealing a significant multivariate main effect for Display, Wilks' Lambda = .06, $F(3, 32) = 166.73$, $p < .01$, $\eta_p^2 = .94$. The univariate output revealed a significant main effect of Display for the depth, $F(1, 34) = 490.52$, $p < .01$, $\eta_p^2 = .94$, direction, $F(1, 34) = 14.05$, $p < .01$, $\eta_p^2 = .29$, and combined judgment data, $F(1, 34) = 110.09$, $p < .01$, $\eta_p^2 = .76$. For all judgment measures mean scores were higher in the video condition than in the animated condition. From this it can be inferred that while contextual information enables performers to anticipate well above chance level, postural information makes a significant additional contribution to anticipation skill.

Reflecting the above effect sizes, the advantage of viewing video as opposed to the animation was greater for depth response accuracy (normal: 82.19%, animated: 67.38%) than for directional judgments (video: 68.89%, animated: 65.89%). This suggests that postural information may be particularly important for anticipating depth. For example, the most useful cues when anticipating drop shots may emerge from the angle and speed of the racket head on approach to racket-ball contact. Abernethy et al. (2008) showed that when players had to anticipate a smash or drop shot in badminton while viewing a point-light display showing only the shuttle and either the racket, the arm, the upper body, or the lower body, the most informative source at racket-shuttle contact for the skilled players was the racket.

We further hypothesised that the increase in accuracy from the animated to the video condition would be more pronounced in the skilled than the less-skilled group, and that skilled participants would be more accurate than their less-skilled counterparts in both video and animated conditions. The MANOVA revealed a significant main effect of Group, Wilks' Lambda = .60, $F(3, 32) = 7.08$, $p < .01$, $\eta_p^2 = .40$, with the univariate analysis indicating a significant group effect for the depth, $F(1, 34) = 7.88$, $p < .01$, $\eta_p^2 = .19$, direction, $F(1, 34) = 11.21$, $p < .01$, $\eta_p^2 = .25$, and combined judgment data, $F(1, 34) = 21.76$, $p < .01$, $\eta_p^2 = .39$. In each case, skilled participants were more accurate than their less-skilled counterparts. The hypothesised Display × Group interaction approached significance overall, Wilks' Lambda = .81, $F(3, 32) = 2.43$, $p = .08$, $\eta_p^2 = .19$, with the univariate analysis revealing a significant Display × Group interaction for direction judgments, $F(1, 34) = 7.07$, $p = .01$, $\eta_p^2 = .17$ (see Figure 2.2). To clarify the source of these findings pairwise comparisons revealed significantly higher accuracy for the skilled group for depth (video: $p < .01$, $d = 1.06$; animated: $p = .02$, $d = 0.70$) and combined (video: $p < .01$, $d = 1.72$; animated: $p < .01$, $d = 0.93$) judgments across both display conditions, while for direction judgments the group effect was significant and large in the video condition ($p < .01$, $d = 1.36$), but smaller and non-significant in the animated condition ($p = .07$, $d = 0.51$). Collectively, these findings confirm that skilled players: a) use postural cues picked up from an opponent to anticipate more effectively than their less-skilled counterparts; (Mann et al., 2007) and b) can use contextual information more effectively than less-skilled participants in the absence of postural cues.

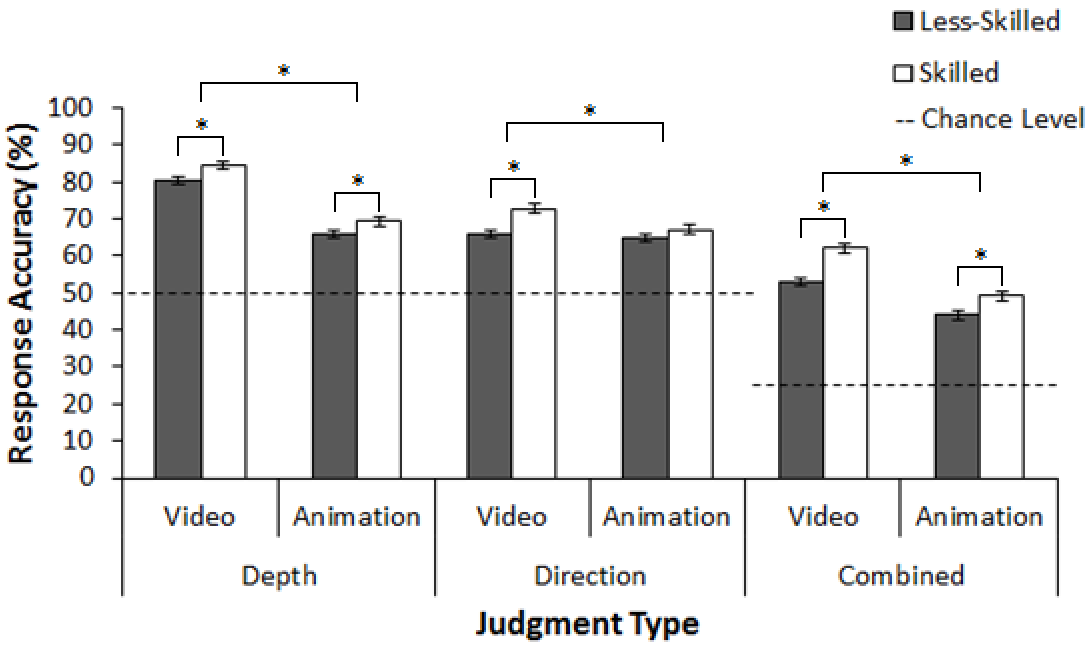


Figure 2.2. Mean (SE) depth, direction and combined response accuracy of skilled and less-skilled participants in video and animated display conditions. *$p < .05$

To summarise, this study demonstrated that both skilled and less-skilled tennis players are able to use contextual information to anticipate more effectively than would be expected due to chance when postural information is not available. This finding is important because tennis players are often required to anticipate in advance of pertinent postural cues becoming available due to extreme time constraints (Triolet et al., 2013). Furthermore, findings indicate that while both skilled and less-skilled players can use contextual and postural information to anticipate more effectively than would be expected due to chance, both groups can use postural information to anticipate more accurately when it is available than when it is not. Moreover, skilled players can use contextual information to anticipate more effectively than less-skilled players in the absence of postural cues. The findings of this study alone however, are not sufficient to understand how skilled performers process contextual information to anticipate more effectively than their less-skilled counterparts.

Study 2

In Study 2, we trace the perceptual-cognitive processes underlying anticipation when constrained to anticipate based on contextual information alone. To understand the processes underpinning skilled anticipation performance, researchers have reproduced the conditions of validated representative anticipation tasks, and collected verbal report and gaze data to aid their understanding of how skilled performers perceive and process information differently to less-skilled performers (e.g., McRobert et al., 2011; North et al., 2011; Roca et al., 2011).

In anticipation tasks in sports other than tennis, when asked to report their thoughts concurrently or retrospectively, skilled performers have been shown to make more verbal statements which are indicative of elaborate domain-specific memory representations which facilitate the retrieval and utilisation of task-specific information from LTM (e.g., McRobert et al., 2009; North et al., 2011). However, no researchers have investigated the processes underpinning skilled performance when constrained to anticipate based on contextual information alone. It is important to note that researchers have demonstrated that tennis players can verbalise their thoughts during performance providing an indication of the information they are attending to (McPherson, 1999, 2000; McPherson & Kernodle, 2007). This body of work, investigating the cognitive processes underpinning skilled performance in tennis, has shown that during competition, skilled players' verbal reports are more detailed and varied than less-skilled players and has provided an indication of the information players attend to during competition. It is also evidence of the utility and effectiveness of verbal reports as a source of data.

Williams and Davids (1997) originally collected verbal reports of thoughts in conjunction with eye-movement data to verify the information participants were attending to in a soccer anticipation task, finding that the relationship between visual fixation and the information participants verbally reported they were attending to, was dependent on the nature of the task. In a task which evoked the use of foveal vision for information extraction, the area of the display fixated on was also verbally reported by participants, whereas when information was extracted through the use of peripheral vision, participants reported attending to different information to that which they were fixating on during the task.

Skilled performers have been shown to exhibit different gaze behaviours to less-skilled performers (e.g., Ward et al., 2002; Williams et al., 2002). While there is a large body of research evidence to indicate that skilled performers use less fixations of longer duration when searching for information in some tasks (Mann et al., 2007), some researchers interested in anticipation in tennis have observed no differences in search rate (numbers of fixations and fixation locations, fixation duration) between high and low-skilled players but instead differences have been demonstrated in the time players spend fixating on various sources of information (Ward et al., 2002; Williams et al., 2002). It has however been recommended that gaze data should be interpreted with caution, as they merely indicate the location of the fovea during task performance, without assessing the potentially important role played by peripheral vision (Mann & Savelsbergh, 2015). In some situations it has been suggested that skilled performers merely adopt an appropriate point upon which to anchor foveal vision. This strategy is thought to accommodate attending to, and processing of task-relevant information picked up from other pertinent areas of the environment through the use of peripheral vision (Ripoll et al., 1995; Vaeyens, Lenoir, Williams, Mazyn, & Philippaerts, 2007; Williams & Elliott, 1999). In such instances, researchers can only make inferences as to what information participants attend to, highlighting the need to collect more direct measures such as verbal reports of thoughts in conjunction with gaze data (Williams & Davids, 1998).

In this study, we compared skilled and less-skilled tennis players' ability to anticipate shot direction and depth when viewing test stimuli in the animated condition, while collecting eye-movement data during trials and immediate retrospective verbal reports of thoughts following selected trials. We used the animated condition as opposed to the video condition because we are interested in the perceptual-cognitive processes underlying anticipation based on contextual information alone, rather than when postural information is available. We hypothesised, based on the findings of Study 1, that both groups would be able to anticipate at levels significantly greater than chance and that the skilled participants would record higher response accuracy scores than their less-skilled counterparts. As skilled participants appear to be able to use contextual information picked up from the display to anticipate more effectively than less-skilled participants, we further hypothesised that the skilled participants in this study would process such information differently to less-skilled participants. Based on LTWM theory (Ericsson & Kintsch, 1995), as well as previous research on anticipation (McRobert et al., 2011; North et al., 2011; Roca et al., 2011), we hypothesised that skilled participants would make more evaluation and prediction statements than less-skilled participants. This finding would be indicative of the skilled participants' more elaborate domain-specific memory representations. We further analysed participants' verbal reports based on domain-specific keywords to provide an indication of the information participants are consciously attending to when presented only with contextual information. We hypothesised that skilled participants' verbal reports would be more detailed and varied than less-skilled participants' (McPherson, 1999, 2000; McPherson & Kernodle, 2007), which would be demonstrated by their use of a greater amount of different keywords than less-skilled participants. Finally, based on previous research on anticipation in tennis, we hypothesised that the skilled and less-skilled participants' search rate would not differ but rather that differences would be observed in the amount of time participants fixate on the various features of the display (Ward et al., 2002; Williams et al., 2002).

Methods

Participants

A total of 10 skilled (M_{age} = 28.6 years, *SD* = 4.7) and 10 less-skilled (M_{age} = 23.7 years, *SD* = 4.4) male tennis players participated in this study. Six of the skilled participants and four of the less-skilled participants had taken part in Study 1. The time period between the two studies was approximately 10 to 12 months. Skilled participants had a mean of 22.0 (*SD* = 5.3) years of playing experience, five of whom held an Association of Tennis Professionals (ATP) singles ranking (mean career high ranking of 788 [*SD* = 559] in the world). Less-skilled participants had a mean of 3.8 (*SD* = 3.9) years of playing experience. Skilled participants had played tennis for a mean of 14.5 (*SD* = 4.2) hours per week throughout their career and competed in a mean of 19.2 (*SD* = 11.9) competitions per year, whereas less-skilled participants had played a mean of 1.6 (*SD* = 1.5) hours per week, and had not competed in competitive tournaments outside of schools tennis. One participant in the skilled group and two participants in the less-skilled group were left-handed with respect to the hand they normally use to play tennis with, whereas all other participants normally use their right hand. As in Study 1, participants gave their informed consent to take part and were informed that they could withdraw at any time without penalty. The research was carried out according to the ethical guidelines of the lead university.

Test Stimuli

A total of 28 trials in the animated display condition, which were shown to positively discriminate between skilled and less-skilled participants in Study 1, were used as test stimuli. The 28 trials were made up of 8 familiarisation and 20 experimental trials. In Study 1, skilled participants had recorded combined response accuracy scores at least 8.75% more accurate than less-skilled participants for each of the 20 experimental trials used. The number of shots played prior to the opponent's occluded shot in trials was between 2 and 12. Trials lasted between 5 and 18 seconds including a still frame that was presented for three seconds prior to the racket-ball contact of the serve at the beginning of the point.

In experimental trials the number of shots played to the four areas of the court on the final occluded shot were: deep-left (8); deep-right (8); short-left (2); and short-right (2). The order of the bounce location of the opponent's final occluded shot was randomised throughout trials. An inter-trial interval of 6 seconds was employed in all trials except the eight trials in which participants were required to provide an immediate retrospective verbal report, with the inter-trial interval being extended until participants had finished reporting their thoughts in those trials.

Materials, Apparatus, and Set-Up

The experimental set-up and visual angle employed was the same as in Study 1. In addition, participants' gaze was recorded using a Mobile Eye eye-tracking system (Applied Science Laboratories, Bedford, MA, USA) during trials. The head-mounted system is integrated in a pair of glasses connected to a digital transmission unit, which is wirelessly connected to the recording device and worn by the participant in a small backpack. The gaze recording system records two images with two separate cameras; an image of the participant's eye and the scene image. The system integrates these two images to create one video recording of the scene video with a superimposed gaze cursor. The gaze data were analysed using ASL Results Plus (Applied Science Laboratories, Bedford, MA, USA). The system is accurate to ± 1° visual angle, with a horizontal and vertical precision of 1°.

Verbal reports of thoughts were recorded using a lapel microphone, a compact diversity receiver, a body-pack transmitter (ew112-p G3; Sennheiser, Wedemark, Germany) and a hand-held recording device (Zoom H5; Zoom Corporation, Tokyo, Japan).

Procedure

Prior to commencing testing, participants were given a brief overview of the experimental protocol. The microphone was attached to the lapel of the participant and the body-pack transmitter to their belt-strap. Participants then took part in between 20 and 35 minutes verbal report training on how to provide retrospective verbal reports of thoughts to ensure participants provided only level 1 and 2 verbalisations (based on Ericsson & Kirk [2001] using an adaptation of Ericsson & Simon's [1993] protocol). According to Ericsson and Simon (1980), Level 1 verbalisations are reports of heeded information, Level 2 verbalisations are reports of information that was heeded but is in some mode other than verbal, such as visual information. Ericsson and Simon (1980) stated that verbal reports should only be made up of Level 1 and 2 verbalisations as the researcher is interested in information processed during the task as opposed to reports of information that is not heeded during the task (Level 3 verbalisations) and is therefore not reported as a result of the cognitive processes underlying performance. The training consisted of instructions on how to report thoughts retrospectively, description of how providing verbal reports differs to normal conversation, and practice providing retrospective verbal reports on generic tasks (for details on training participants to provide valid verbal reports of thoughts, see Eccles, 2012). The training was designed to encourage participants to only report Level 1 and 2 verbalisations through feedback about the verbal reports they gave during these tasks. Participants were encouraged to ask questions throughout the training and were provided with good and bad examples and the difference between such examples, of retrospective verbal reports based on these tasks.

Following the verbal report training, participants were fitted with the gaze recording system, placing the eye-tracking glasses on their head and the digital transmission unit in a small backpack on their back. The system was calibrated using seven non-linear calibration points presented as a grid on the visual display which encompassed the entire area of the display participants could potentially fixate on. This procedure was undertaken to ensure that the participants' point of gaze was accurately recorded. Calibration of the system was checked prior to starting the familiarisation trials, between familiarisation and experimental trials, and periodically during testing.

Following calibration of the gaze recording system, participants viewed eight familiarisation trials from a distance of 5 m. Trials were occluded at the opponent's racket-ball contact, at which point participants responded in the same way as in Study 1. Participants were then asked to provide an immediate retrospective verbal report of their thoughts following each of the familiarisation trials. The same procedure was in place for the 20 experimental trials; however participants only provided a verbal report of their thoughts when asked to, following eight randomly ordered trials (the eight most discriminating trials from Study 1). All participants provided verbal reports on the same eight trials. The testing protocol was completed within 60 minutes.

Data Analysis

Response accuracy data

The number of correct trials out of twenty was expressed as a percentage with respect to depth, direction, and combined judgments. One-sample *t*-tests were conducted to compare response accuracy scores of the two groups with what would be expected due to chance. Independent *t*-tests were conducted to determine differences in response accuracy between groups with percentage of correct depth, direction, and combined judgments serving as dependent variables.

Verbal report data

The verbal reports provided in the experimental trials were transcribed and coded using Ericsson and Simon's (1993) protocol analysis method, further developed by Ward (2003). Reports were initially segmented using natural speech and other syntactical markers. Reports were then coded as being made up of three statement types: *monitoring* statements which were coded as all statements in which participants recalled current actions or events; *evaluation* statements, which were all statements in which participants assessed the situation relative to a specific event; and *prediction* statements, which were all statements in which anticipation of future or potential future events was evident (Ericsson & Simon, 1993). These three categories were used due to their use in previous studies on anticipation using verbal reports. Moreover, these categories have been successfully employed to interpret the cognitive processes underpinning expertise. Using the same coding system would therefore allow us to compare our findings with those of other related studies. Pairwise comparisons were first conducted to determine whether there was a difference in the length of verbal reports (number of words) made by skilled and less-skilled participants. This procedure was undertaken to ensure that any differences were due to the quality and/or type of participants' reports as opposed to the length of their reports. Next, to examine the type of verbal statements used by skilled and less-skilled participants, a 2 × 3 (Group [skilled, less-skilled] × Statement Type [monitoring, evaluation, prediction]) ANOVA was conducted, with Group as the between-participant factor and Statement Type as the within-participant factor. Finally, pairwise comparisons were conducted to investigate differences between participants in the type of statement made.

To conduct an initial investigation of what sources of contextual information participants were using from the display to inform their judgments a bespoke domain-specific keyword coding/categorisation system was developed. Roca et al. (2013) used a similar approach when identifying interactions between the perceptual-cognitive skills underlying anticipation in soccer. Keywords were broken down into six categories: player positioning keywords which referred to the movement and positioning of the players; court geometry referring to the angles and spaces presented between players; shot type referring to any type of shot used in tennis (e.g., forehand/lob); ball flight referring to the speed, spin, and height of shots hit; shot placement referring to the depth and direction of a player's shot; and balance of power referring to the tactical situation within the rally. Once keywords were coded within reports, the percentage of participants' reports containing each of these keywords was calculated. A 2 × 6 (Group × Keyword Type [player positioning, court geometry, shot type, ball flight, shot placement, balance of power]) ANOVA was conducted, with Group as the between-participant factor and Keyword Type as the within-participant factor.

Gaze data

Search rate data were made up of the mean number of fixations, mean number of fixation locations, and mean fixation duration. A fixation was defined as the participant's point of gaze staying stationary for three frames or more (>/= 100 ms) within 1.5° of movement tolerance (see Williams & Davids, 1998). To determine any between-group differences, independent *t*-tests were conducted for search rate, with mean number of fixations, mean number of fixation locations, and mean fixation duration as the dependent variables and Group as the independent variable.

Percentage viewing time was defined as the portion of time the participant spent fixating on a particular area of interest. Areas of interest were: the (receiving) player; the opponent; the ball flight; the near side of the court; the far side of the court; and the play area (any other area of the display within which the ball could potentially travel throughout the trial); and unclassified areas. Unclassified fixations were subsequently omitted from the analysis as they made up less than 1% of total fixation time. Ball flight as opposed to the ball alone was used as an area of interest. The ball flight area of interest subtended a visual angle of 6.0° in the direction the ball was travelling and 1.2° in the corresponding perpendicular plane, thus encompassing when participants were looking at the ball as well as if they made a visual saccade to where the ball was going to bounce or be played to (Croft, Button, & Dicks, 2010; Singer et al., 1998), and if participants' gaze lagged behind the ball (Land & McLeod, 2000). The size of the shape used to identify when participants' gaze was on ball flight was maintained constant throughout the analysis. To examine the amount of time skilled and less-skilled participants spent viewing the various areas of the visual display, a 2 × 6 (Group × Fixation Location [player, opponent, ball flight, near side, far side, play area]) ANOVA was conducted with

Group as the between-participant factor and Fixation Location as the within-participant factor.

The first author analysed all trials, and conducted further analysis to determine intra-observer reliability one week later. Inter-observer agreement was conducted by an independent investigator. Intra- and inter-observer reliability for verbal report and gaze data ranged from 84% to 93% (see Thomas, Nelson, & Silverman, 2005 for procedures used to determine intra- and inter-observer reliability).

The Greenhouse-Geisser correction was employed in the case of violations of Mauchly's test of sphericity. Partial eta squared (η_p^2) values are reported for effect size of main effects and the alpha level of statistical significance for all tests was set at .05 with the sequential Bonferroni correction applied to control for family-wise error where multiple *t*-test comparisons were conducted. Pairwise comparisons were carried out in the case of significant interactions and main effects. Cohen's *d* is reported for effect size of these comparisons.

Results and Discussion

Response Accuracy Data

We hypothesised, based on the findings of Study 1, that both skilled and less-skilled participants would anticipate at levels significantly greater than chance, and that the skilled participants' judgments would be more accurate than the less-skilled participants'. Mean percentage scores and standard errors for response accuracy of both skilled and less-skilled groups are presented in Figure 2.3. Both skilled and less-skilled participants' response accuracy scores for depth, direction, and combined judgments were significantly higher than would be expected due to chance ($p < .01$). This finding reaffirms the ability of tennis players to use contextual information to anticipate effectively when postural information is not available, signifying the important role this form of information plays in anticipation (Abernethy et al., 2001; Triolet et al., 2013). This finding is particularly important due to the extreme time constraints experienced during fast ball sports such as tennis which mean it may not always be feasible for players to wait for pertinent postural cues to become available. Skilled participants were significantly more accurate than less-skilled participants when making depth ($p < .01$, $d = 1.59$) and combined ($p < .01$, $d = 1.86$) but not direction ($p = .20$, $d = 0.32$) judgments.

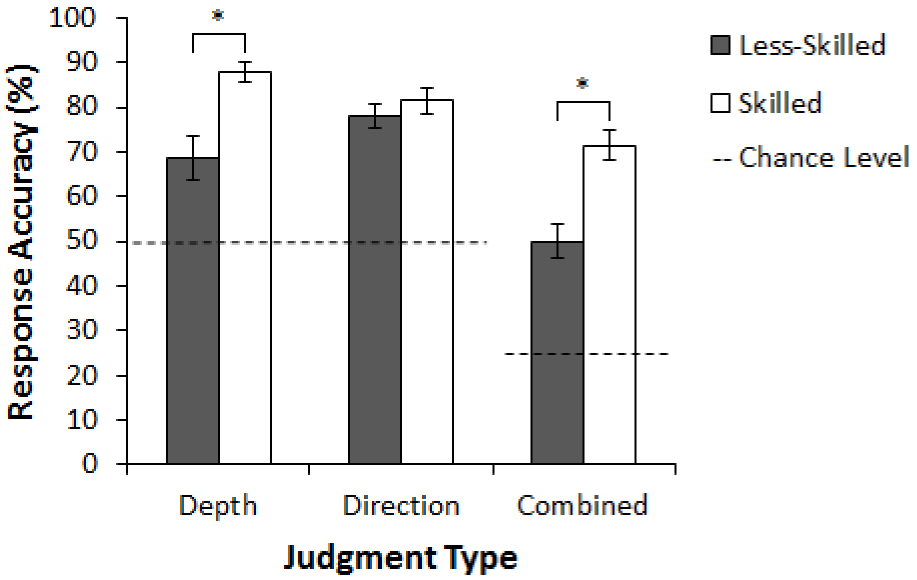


Figure 2.3. Mean (SE) depth, direction and combined response accuracy across groups in the animated display condition. $^*p < .05$

Verbal Report Data

Statement Type

First, pairwise comparisons revealed no significant difference between the number of words contained in skilled and less-skilled participants' verbal reports ($p = .28$, $d = 0.27$). Any differences that may be observed between or within groups are therefore a result of the quality or type of report provided as opposed to the report length. We hypothesised, based on LTWM theory (Ericsson & Kintsch, 1995) and previous research on anticipation (McRobert et al., 2011; North et al., 2011; Roca et al., 2011), that skilled participants would make more evaluation and prediction statements than their less-skilled counterparts. Mean number of statements and standard errors are presented in Figure 2.4. There was no significant Group × Statement Type interaction, $F(1.22,22.01) = .60$, $p = .48$, $\eta_p^2 = .03$, however a main effect of Statement Type was observed, $F(1.22,22.01) = 4.60$, $p = .04$, $\eta_p^2 = .20$. No main effect of Group was observed, $F(1,18) = .53$, $p = .48$, $\eta_p^2 = .03$. Pairwise comparisons for Statement Type revealed that participants made significantly more monitoring ($M = 10.10$, $SE = 2.09$) and prediction ($M = 6.6$, $SE = .54$) than evaluation ($M = 4.25$, $SE = .68$) statements ($p = .04$, $d = 0.86$, and $p = .02$, $d = 0.81$ respectively). To test our *a priori* prediction that the skilled group would use more evaluation and prediction statements than the less-skilled group, we conducted two planned contrasts. In support of Ericsson and Kintsch's (1995) LTWM theory, the first of these revealed significant differences between skilled ($M = 5.60$, $SE = .87$) and less-skilled groups ($M = 2.9$, $SE = 1.04$) for evaluation statements ($p = .03$, $d = 0.89$), while the difference between skilled ($M = 7.4$, $SE = .52$) and less-skilled ($M = 5.8$, $SE = .94$) groups for prediction statements was not significant, ($p = .08$, $d = 0.66$). Findings indicate that when presented with only contextual information, skilled participants appear to evaluate the situation and potential outcomes more effectively than their less-skilled counterparts. This effect potentially contributes to their more accurate anticipation judgments when constrained to anticipate based on contextual information alone.

Our findings are in support of previous research which has shown that skilled performers make more statements which are indicative of more elaborate memory representations, that is more evaluation statements. Although the difference between groups in the amount of prediction statements made did not reach statistical significance, the observed effect size was medium to large. We therefore suggest that similar cognitive processes underlie skilled anticipation when constrained to use contextual information alone as when postural information is readily available for processing (McRobert et al., 2009; North et al., 2011; Roca et al., 2011). Skilled participants are likely to have regularly encountered similar situations and as such may have developed elaborate memory representations from which they can access information for evaluative purposes. When skilled participants perceive contextual information in the form of sequential relative movements of the players and the ball flight in the lead up to the event, it is possible that some feature(s) picked up from the display, may act as a retrieval cue, which is activated to retrieve task-relevant information from LTM. This information potentially helps guide participants' judgments by allowing for more thorough evaluation of the event, and prediction of potential event outcomes, relative to previously experienced situations. While previous research on anticipation has always presented participants with postural information which could act as the retrieval cue needed to anticipate more effectively, our findings indicate that skilled performers may be able to use some form of contextual information as a retrieval cue to access pertinent task-relevant information from LTM during anticipation.

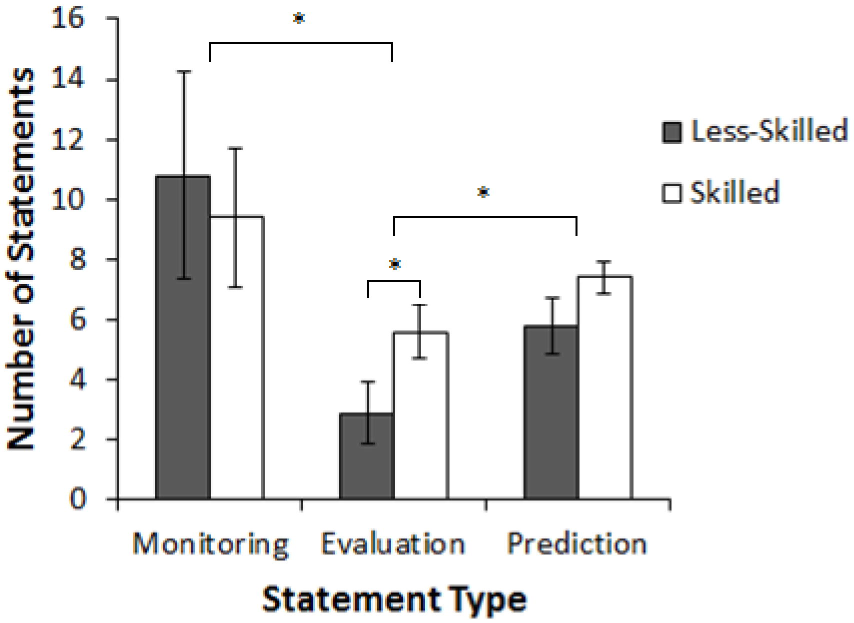


Figure 2.4. Mean (SE) number of verbal statements made by skilled and less-skilled participants. *$p < .05$

Keyword Type

Based on the research of McPherson and colleagues (McPherson, 1999, 2000; McPherson & Kernodle, 2007), we hypothesised that skilled participants' verbal reports would be more detailed and varied than less-skilled participants'. To analyse the Keyword Type data we first calculated the percentage of participants' reports containing each type of keyword. These data are presented in Figure 2.5. ANOVA revealed the Group × Keyword Type interaction did not reach statistical significance, $F(2.92,52.62) = 2.46$, $p = .07$, $\eta_p^2 = .12$, however significant main effects of Group, $F(1,18) = 5.99$, $p = .03$, $\eta_p^2 = .25$ and Keyword Type, $F(2.92,52.62) = 19.56$, $p < .01$, $\eta_p^2 = .52$, were observed. The main effect of Group indicates that, in line with our hypothesis, skilled participants used a greater number of different keywords per report ($M = 2.73$, $SE = .22$) than less-skilled participants ($M = 1.94$, $SE = .24$).

Further independent *t*-tests revealed that significantly more of the skilled participants' reports contained court geometry ($p < .01$, $d = 1.28$) and shot type ($p < .01$, $d = 1.30$) keywords. This finding provides an indication of the sources of information consciously attended to by skilled participants when constrained to anticipate based on contextual information alone, as would be the case under extreme time constraints, providing a novel contribution to the research literature. When less-skilled participants were making statements containing player positioning keywords such as *"I shot to the left hand side of my opponent, and I moved towards the net"*, in the same trial skilled participants were making statements containing court geometry and shot type keywords such as *"The space was on the left hand side for an angled passing shot"*. It appears that the skilled participants are better able to use domain-specific information picked up from the relative movement and positioning of the two players to form meaningful evaluations about the availability of spaces and angles between players and the resultant potential shot selections of the opponent, as opposed to merely monitoring the players' positioning on the court. Furthermore, while the type of shot being played (e.g., forehand lob) is not immediately apparent from the visual display as the players' bodies and rackets are not visible, skilled participants appear to infer the type of shot being hit based on the information presented. Knowledge of the type of shot usually hit from a particular position on the court may allow the skilled players to more effectively evaluate the situation and interpret the tactical intentions of the opponent.

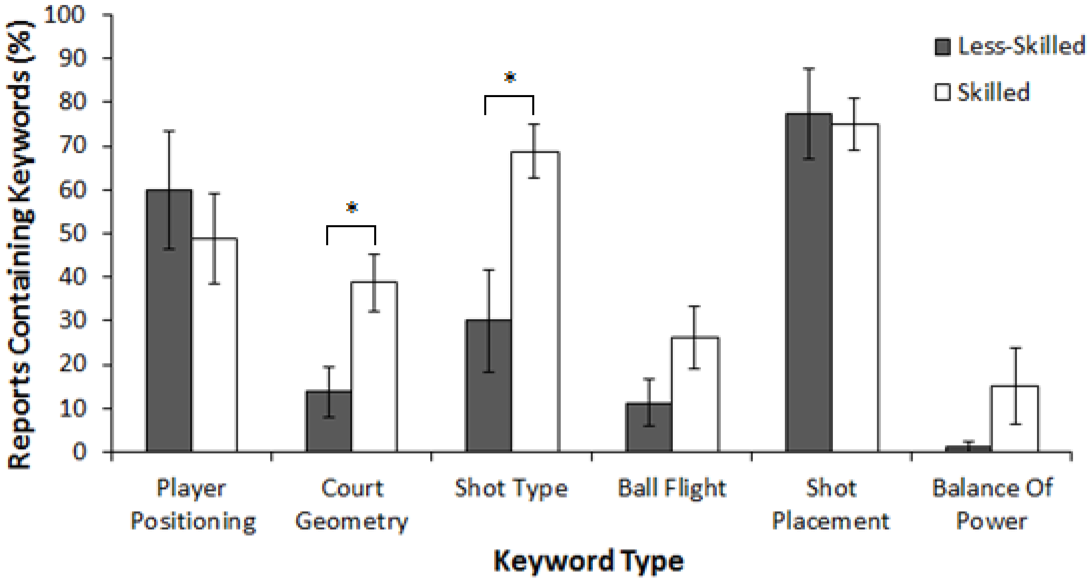


Figure 2.5. Mean (SE) percentage of reports containing keywords for skilled and less-skilled participants. *$p < .05$

Gaze Data

Search Rate

We hypothesised based on previous research on anticipation in tennis (e.g., Ward et al., 2002; Williams et al., 2002), that no differences would be observed in search rate between groups and the differences would, in contrast, exist in the amount of time participants spent fixating on particular areas of the display. Pairwise comparisons revealed that skilled participants fixated on significantly fewer of the six potential fixation locations per trial than less-skilled participants (M = 4.15, SE = .13 vs. M = 4.67, SE = .20, p = .02, d = 1.04). No differences were observed between groups for mean number of fixations or mean fixation duration. The data showing that skilled participants fixated on significantly fewer areas of the display per trial potentially indicate that skilled participants employed a more selective and, as such, more efficient gaze behaviour than less-skilled participants (Williams & Davids, 1998). However, it must be noted that while the effect size of this difference is large, the between-groups difference is small (approximately half of a fixation location per trial). We therefore draw conclusions from these data tentatively.

Percentage Viewing Time

Mean percentage viewing time and standard errors are presented in Figure 2.6. ANOVA revealed a significant Group × Fixation Location interaction, $F(3.10,49.54) = 3.98$, $p = .01$, $\eta_p^2 = .20$, and a main effect of Fixation Location, $F(3.10,49.54) = 17.37$, $p < .01$, $\eta_p^2 = .52$. Bonferroni-adjusted pairwise comparisons revealed that participants fixated the ball flight more than any other area. As hypothesised, differences were observed between groups for the amount of time spent fixating on the various features of the display. Pairwise comparisons revealed that skilled participants fixated Ball Flight for a greater percentage of time ($M = 42.55\%$, $SE = 3.63$ vs. $M = 24.07\%$, $SE = 4.58$, $p < .01$, $d = 1.50$) than less-skilled participants. It is important to reiterate that we can only infer from gaze data the information participants may be processing from the visual display. It is possible that the skilled participants fixated for a greater amount of time on ball flight because they perceived this to be the most useful form of information available. However, based on previous findings (e.g., Ripoll et al., 1995; Vaeyens et al, 2007), it is possible that they are strategically anchoring gaze on the ball flight to more effectively extract and process pertinent information about the movement of the players relative to each other and the ball. Anchoring gaze on the ball flight may have allowed the skilled participants to more effectively extract informative cues arising from the relative movement and subsequent positions of the players through the use of peripheral vision. While skilled participants fixated on ball flight for a greater amount of time than any other area of the display, this attention to ball flight information is not evident in their verbal reports, in which ball flight is referred to comparatively little. Although skilled participants are fixating for the longest amount of time on ball flight in this task, they may be concurrently attending to other, more important information from the display (cf., Williams & Davids, 1997). These data, in conjunction with the verbal report data, provide an initial indication of the sources of contextual information skilled tennis players fixate on and attend to when anticipating based on contextual information alone.

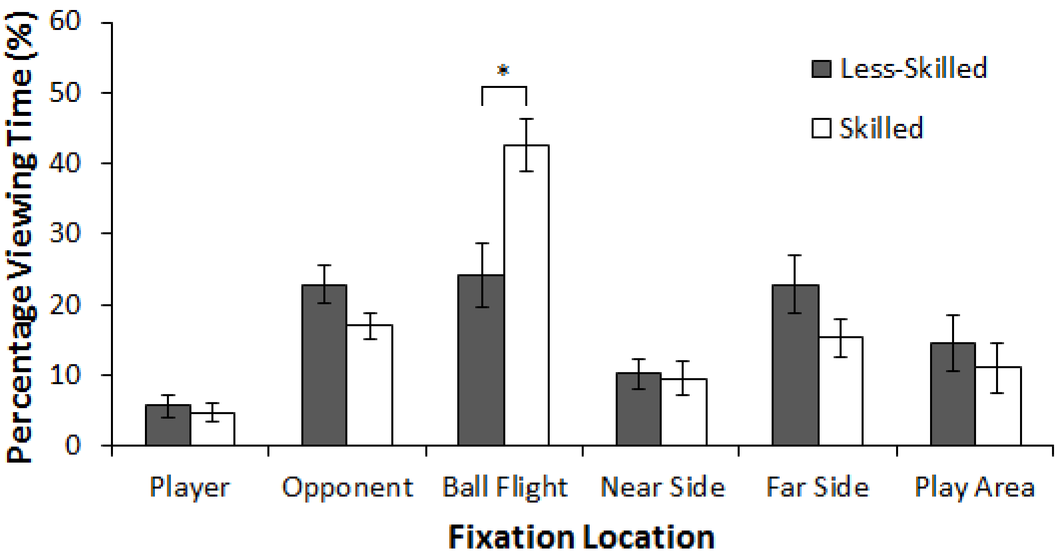


Figure 2.6. Mean (SE) percentage viewing time relative to fixation location of skilled and less-skilled participants. *$p < .05$

To summarise, this study reaffirmed the importance of contextual information in anticipation. We demonstrated that skilled tennis players process contextual information differently to, and in essence, more effectively than less-skilled players. In support of LTWM theory (Ericsson & Kintsch, 1995), skilled participants were shown to make more evaluation statements which are indicative of skilled participants' more elaborate domain-specific memory representations. The verbal reports of skilled participants were more detailed and varied relative to domain-specific keywords when compared with less-skilled counterparts. Furthermore, gaze behaviours differed between skill groups, with skilled participants fixating on the ball for greater amounts of time than the less-skilled participants. We tentatively proposed that skilled participants employed a visual anchoring strategy to more effectively extract pertinent information from the display through the use of peripheral vision.

General Discussion

We examined the ability of skilled and less-skilled tennis players to anticipate the depth and direction of an opponent's shot when postural information was either retained or omitted from the visual display, such that participants were constrained to anticipate based on the sequential relative movements of the players and the ball flight alone, or this information as well as postural information. We provided a novel contribution, investigating whether or not participants could anticipate effectively based on contextual information alone, as would be the case when constrained to anticipate in advance of pertinent postural cues becoming available due to extreme time constraints. We hypothesised, based on previous research (Abernethy et al., 2001; Triolet et al., 2013), that participants would be able to use this form of contextual information to anticipate effectively, and that the findings would indicate the extent to which they could do so relative to when postural information was also available. Moreover, we expected skilled participants to be able to use this information more effectively than their less-skilled counterparts (Abernethy et al., 2001). We further aimed to contribute to the development of psychological theory by investigating the perceptual-cognitive processes underlying anticipation when constrained to anticipate based on contextual information alone. We hypothesised, based on LTWM theory (Ericsson & Kintsch, 1995), that skilled participants would make more evaluation and prediction statements which would be indicative of more elaborate domain-specific memory representations and that skilled participants' gaze behaviour would differ to that of less-skilled participants, in relation to the amount of time spent viewing the various features of the display (Ward et al., 2002; Williams et al., 2002).

First, both groups of tennis players were able to anticipate at levels greater than chance when constrained to anticipate based on contextual information alone, with skilled and less-skilled groups recording a mean combined judgment score of 60.30% and 47.00% over the two studies respectively. These high response accuracy scores provide a clear indication of the importance of this form of contextual information in anticipation. This finding is novel since previously researchers have only been able to infer that contextual information may be used in isolation to anticipate effectively since postural information has always been available to participants (e.g., Abernethy et al., 2001; Triolet et al., 2013). We report the first attempt to remove postural information from the display such that the extent to which performers can use contextual information to anticipate could be more directly examined.

Second, our findings illustrate that while contextual information in the form of the sequential relative movement of the players and the ball flight is an important source of information that can be used to anticipate effectively by skilled and less-skilled performers, the accuracy of participants' anticipation judgments increases substantially when they are also provided with postural information from the opponent, revealing an additive effect of both sources of information. Loffing et al. (2011) found an effect in the opposite direction (i.e., that when tennis players were provided with contextual information in the form of court positioning in addition to postural information, the accuracy of their judgments increased in comparison with when postural information was presented in the absence of contextual information). It is likely that the information upon which performers base their anticipation judgments in a real-world task is situation dependent (Roca et al., 2013) and that they conceivably opt for the most reliable source of information available. The findings of Triolet et al. (2013) indicate that in professional tennis, when players feel anticipation is necessary to avoid losing the point, they may only be able to wait for pertinent postural cues to become available on a small number of instances due to the extreme time constraints involved. It is therefore likely, and it seems strategically viable, that players continuously process contextual information to inform potential anticipation judgments throughout rallies, acting on these advanced judgments in the case of severe time constraints, and calling upon more reliable postural information from the opponent, if the time taken to reach the opponent's shot is predicted to be less than it would take for the ball to pass the player.

Third, we have demonstrated how skilled tennis players more effectively process contextual information to anticipate with greater accuracy than their less-skilled counterparts. Skilled players appear to more effectively extract pertinent contextual information picked up from the visual display. This information may act as a retrieval cue, which is activated to retrieve task-relevant information from LTM, resulting in more effective evaluation of the presented information and potential outcomes of the opponent's upcoming shot. While these data provide an indication of how skilled performers process contextual information in the absence of postural information, LTWM theory predicts that when task-relevant options exist, skilled performers would be expected to generate a greater number of task-relevant options than less-skilled performers (Ward et al., 2013). An interesting line of research would therefore be to investigate how contextual and postural information interact with respect to option generation, as this has the potential to provide useful information for the design of testing and training protocols. It is possible though, that in the competitive environment skilled performers would generate more task-relevant options than less-skilled performers far in advance of the event based on the contextual information available (information that in absence of pertinent postural cues can be used to anticipate effectively), and that the perceived feasible options would become fewer but more reliable in the build-up to the event due to the availability of pertinent postural cues.

Although we have found that contextual information picked up in the form of the sequential relative movements of the players and the ball flight in the lead-up to the event, along with the resulting court positioning of the players at the moment of the event is a useful source of information which can be exploited by both skilled and less-skilled tennis players, we do not yet know what information specifically participants use to inform their judgments. For example, the gaze data indicated that skilled participants fixated for longer on the ball flight than their less-skilled counterparts, whereas the verbal report data indicated that skilled participants attended more to court geometry and shot type than their less-skilled counterparts. While it is possible that the ball flight is the most important and informative source of information available from the display, it is possible the relative positioning of the two players at the moment of racket-ball contact may provide the most useful information. In a similar way to how researchers manipulated point-light displays to determine the most informative sources of biological motion information picked up from an opponent (e.g., Cañal-Bruland, van Ginneken, van der Meer, & Williams, 2011; Huys et al., 2009), there is a need for further research which manipulates the visual display to facilitate evaluation of the role and importance of the various sources of contextual information contained within rallies. Such an investigation would not only enhance our knowledge of perceptual-cognitive expertise but enable recommendations to be made as to what information developing players should attend to in anticipation training programs. Moreover, while researchers have demonstrated the effectiveness of anticipation training programs in both laboratory and field-based settings (Abernethy, Schorer, Jackson, & Hagemann, 2012; Williams et al., 2002), only one study to our knowledge has trained participants to use contextual information when anticipating (Mann et al., 2014).

In recent years there has been a shift towards, and a call for, more research investigating the multidimensional nature of anticipation (Cañal-Bruland & Mann, 2015). For example, Roca et al. (2013) provided an illustration of how the perceptual-cognitive skills and processes underlying anticipation interact as a function of the unique task constraints placed on the performer. The number of research studies investigating how contextual information contributes to anticipation is increasing (e.g., Crognier & Féry, 2005; McRobert et al., 2011) and the work of Triolet et al. (2013) has provided us with behavioural evidence of the use of contextual information in a real-world setting. The present paper not only adds to a growing body of work in this area, but through the use of a novel methodological approach, and multiple process-tracing measures has been able to determine with much more certainty, if and how, performers utilise and process contextual information to inform their anticipation judgments.

The viewing perspective employed in this study may be considered to be a limitation in the study design as footage does not replicate the first person viewing perspective normally experienced in tennis. However, to examine the importance of contextual information presented as the sequential relative movement of players and the ball flight in the lead up to the event, it was necessary for participants to be able to see both players and how the velocities of their movements and positions on the court changed relative to the ball and each other throughout the rally. Additionally, while the third person perspective used is not that which would be experienced in a match situation, the relevant information presented is the same as that which would be available in a match (e.g., player positioning/velocity of movement/previous shots hit) albeit in a different form. Moreover, we report significant differences in anticipation across skill groups providing construct validity for the approach. On a similar point, while our gaze behaviour data may not exactly replicate those which would be reported in an on-court setting (e.g., Mann, Farrow, Shuttleworth, & Hopwood, 2009), our findings suggest that skilled participants employed more effective gaze behaviours than their less-skilled counterparts. Furthermore, participants fixated on the player on the near side of the screen a mere 5.15% of total viewing time and only mentioned the near player approximately once per trial in their verbal reports, meaning that only a small amount of time was spent fixating on and attending to the one element of the display that would not be visible in a real-world scenario.

Due to technological limitations, there were differences between the video and animated display condition other than the mere omission of postural information in the animated condition. Other information such as the environmental surroundings, the crowd viewing the match, and the umpire were present in the video condition but not in the animated condition and we therefore cannot assume that the higher response accuracy scores reported in the video condition in comparison with the animated condition are solely a result of the additional postural information that participants were presented with. However, based on anticipation research to date (for a review, see Mann et al., 2007) we considered postural information to be the source of information with the most potential to inform participants' anticipation judgments that was present in the video but not the animated condition.

A further limitation of the present study is the relatively small sample size that compromises the statistical power of our analyses. The difficulty associated with recruiting very highly-skilled athletes, particularly in individual as opposed to team sports, is a common issue faced by researchers in this area. In practice it means that only larger effect sizes will attain statistical significance. In the studies presented here, we were able to use the same number or more participants than in several related studies (e.g., Abernethy et al., 2001; Farrow & Reid, 2012; McRobert et al., 2011) while being fewer than in others (e.g., Loffing et al., 2011; Loffing & Hagemann, 2014). Accordingly, additional research is needed to determine whether comparisons that resulted in small or medium effect sizes are replicated, thereby allowing us to more confidently infer associated small or medium effects in the population. Conversely, statistically significant findings in the present study reveal large effects in comparisons between high-skilled players and less-skilled but experienced players rather than novices. They are therefore good candidates for having practical as well as statistical significance.

In conclusion, we used a novel experimental design to demonstrate that contextual information picked up from the sequential relative movement of the players and the ball flight in the lead up to the event effectively informs anticipation and that these judgments are made more accurate upon presentation of postural information. Due to the extreme time constraints involved in tennis, players may not always be afforded the opportunity to wait for pertinent postural cues to become available. As such the ability to accurately anticipate based on contextual information in advance of such cues may prove to be a key contributing factor to expert performance in time-constrained domains. Furthermore, we found that skilled tennis players employed different gaze behaviours and more thoroughly evaluated this form of contextual information to anticipate more accurately than their less skilled counterparts. Finally, effective use of contextual information may not only ‘set the scene’ for accurate anticipation when pertinent postural cues becomes available, but crucially it may allow for highly accurate anticipation when extreme time constraints mean that waiting several moments longer is not a feasible option.

Chapter 3

The sources of contextual information contributing to skilled anticipation

Abstract

In dynamic, temporally-constrained tasks, individuals often need to anticipate what will happen next prior to information becoming available within the environment. In such situations, the availability of contextual information can facilitate anticipation. While many researchers have identified the specific sources of postural information facilitating anticipation, comparatively few have investigated the specific sources of contextual information that do so. In two studies, we presented skilled and less-skilled tennis players with animations of rallies from real matches that omitted access to postural information from the opponent, constraining participants to anticipate based on contextual information alone. In Study 3, participants anticipated the outcome of an opponent's shot in three conditions in which the sequence length preceding the same occluded shot was varied. Participants anticipated shot direction more accurately when the preceding shot sequence was presented than not. In Study 4, we presented animations that depicted the ball, the players, or both, in either dynamic or still form. Those conditions in which only the ball was depicted yielded the lowest direction response accuracy scores. It appears that both player and ball motion are required to provide the context under which skilled performers can consciously pick up and utilise information to anticipate more accurately than less-skilled counterparts.

Introduction

At the highest levels of performance in dynamic, temporally-constrained domains, such as military combat, sport, and law enforcement, performers often have to make quick and accurate judgments based on minimal information. It is well established that skilled performers extract and utilise postural information to anticipate the opponent's intentions more effectively than their less-skilled counterparts (e.g., Abernethy & Russell, 1987; Williams & Burwitz, 1993). Additionally, researchers have identified the specific sources of postural information used to do so, for example, the hips in the soccer penalty kick (Causer et al., 2017), or the arm and racket in the tennis serve (Jackson & Mogan, 2007). In fast ball sports, the time taken to process and respond to ball flight information often exceeds the time it takes for the ball to pass the receiving player (Singer, 2000; Williams, Davids, & Williams, 1999), and under particularly extreme time constraints, the same may even be true when responding based on pertinent postural cues picked up some brief moments prior to event occurrence (Triolet et al., 2013). When skilled performers are not afforded the time to wait for pertinent postural cues to become available from the opponent's emerging movement pattern, they are thought to rely on contextual information to anticipate the opponent's intentions (Abernethy et al., 2001; Müller & Abernethy, 2012). In this paper, we focus on determining the extent to which performers can use different sources of contextual information (shot sequencing, player and ball motion and positioning) to anticipate independent of pertinent postural cues.

Buckolz et al. (1988) suggested that two types of information can be used to anticipate the intentions of an opponent; postural and contextual information. Postural information arises from the movement pattern of the opponent, whereas contextual information is available prior to pertinent postural cues becoming available. Moreover, contextual information remains available as the movement pattern of the opponent develops. Buckolz et al. originally suggested that contextual information exists in numerous forms such as knowledge of the opponent's strengths and weaknesses, climatic conditions, and the relative positioning of the players on the playing terrain. In recent years, researchers have begun to investigate how certain sources of contextual information such as score-dependent patterns of play (Farrow & Reid, 2012), knowledge of an opponent's action tendencies (Navia et al., 2013), or court positioning of the opponent (Loffing & Hagemann, 2014) influence anticipation judgments in skilled performers. These studies have reported that skilled performers in particular, can utilise this information to adjust their expectancies relating to upcoming events.

It is thought that as a result of their extended experience within a domain skilled performers develop Long Term Working Memory (LTWM) skills (Ericsson & Kintsch, 1995), which allow rapid access to, and retrieval of, information stored in Long Term Memory (LTM). Skilled performers can encode the presented information and associate it with a retrieval cue in Short Term Memory (STM), which allows access to information in LTM about the relationship between the presented information and potential event outcomes. These retrieval structures allow skilled performers access to task-relevant options, which can be evaluated to inform an accurate judgment rather than merely prescribing a set response (Ericsson et al., 2000). In the aforementioned studies (e.g., Loffing & Hagemann, 2014), skilled performers were shown to adjust their expectancies of potential event outcomes based on contextual information available in addition to emerging postural cues, the suggestion being that their more advanced domain-specific knowledge facilitates integration of pertinent contextual information into the anticipation process.

Skilled performers, in particular, appear able to make remarkably accurate anticipation judgments in advance of pertinent postural cues becoming available. For example, skilled performers have been shown to accurately anticipate the outcome of an opponent's shot approximately 580 ms and 720 ms prior to the opponent striking the ball in squash (Abernethy et al., 2001) and tennis (Triolet et al., 2013), respectively. Triolet et al. (2013) observed that highly skilled tennis players often began to respond to the opponent's shot early because they were placed under extreme time constraints, for example, when the opponent was attacking from inside the court. Abernethy et al. (2001) suggested that these accurate anticipatory movements were likely to be due to the use of contextual information picked up from sources such as the preceding shot sequence.

Murphy et al. (2016) sought to clarify whether contextual information can facilitate anticipation independent of postural information. As well as viewing video footage of rallies from real tennis matches, skilled and less-skilled tennis players viewed animations of the same rallies, in which each of the players were replaced by a cylinder and their rackets were not visible. When viewing the animations, participants were constrained to anticipate based on contextual information alone, eliminating the possibility that their judgments could be based on very early occurring postural cues. Although participants anticipated more accurately when viewing the video footage, both groups were more accurate than chance when viewing the animations, with the skilled participants being most accurate. This is further indication (see Abernethy et al., 2001; Triolet et al., 2013) that when skilled performers need to anticipate in advance of pertinent postural cues becoming available, they can draw upon contextual information to do so. Murphy et al. suggested that even when constrained to anticipate based on contextual information alone, skilled participants were able to access associated task-relevant information from LTM, which facilitated more accurate anticipation than less-skilled participants.

Skilled racket sports players have been shown to play specific shots in response to certain shot sequences (McGarry & Franks, 1996). In each of the research studies conducted by Abernethy et al., (2001), Triolet et al. (2013), and Murphy et al. (2016) participants had access to contextual information that could, potentially, be picked up from the shot sequence preceding the to-be-anticipated shot, with the sequence length varying from trial to trial. This approach is in stark contrast to most research on anticipation to date, in which participants have either been presented with isolated actions such that information about the preceding sequence of events is unavailable (e.g., the serve in tennis [Jackson & Mogan, 2007]; the bowl in cricket [Müller et al., 2010]; the penalty kick in soccer [Savelsbergh et al., 2002]) or with sequences that have been presented for a fixed period of time or number of events (e.g., in basketball [Ryu, Abernethy, Mann, Poolton, & Gorman, 2013]; in football [Roca et al., 2011]). In such experimental set-ups, the influence that the preceding sequence of events may have on anticipation is controlled or ignored. Only a few researchers have attempted to determine how having access to the preceding sequence of events influences performance.

Gray (2002a, 2002b) used a simulated baseball batting task to demonstrate that the expectancies of college level baseball batters are influenced by the preceding sequence of pitches. For example, when three fast pitches were followed by a fast pitch, their batting was more accurate than if the three fast pitches were followed by a slow pitch. Loffing et al. (2015) presented skilled and novice volleyball players with sequences of four attacking shots which had been manipulated to either always present smashes, lobs, or an alternating pattern of the two shots prior to anticipating a shot which was either congruent or incongruent with the preceding sequential pattern of shots played. Their findings suggested that expectations of action outcomes were more strongly affected by these sequences for skilled compared with less-skilled participants.

It has also been demonstrated that skilled performers are better than less-skilled performers at picking up repeated patterns in an opponent's game to facilitate anticipation

(Farrow & Reid, 2012; Milazzo et al., 2015). McRobert et al. (2011) presented skilled and less-skilled cricket batters with videos of six "fast" and "slow" bowlers presented in a random order or videos of four "fast" bowlers presented in blocks, such that they viewed each of the four bowlers for six bowls in a row. Performance levels were higher when viewing the same bowler over repeated trials. The authors observed that skilled batters adapted their gaze behaviour when repeatedly viewing the same bowler. They suggested that the contextual information provided by the preceding actions of the bowler allowed the skilled performers to adapt their gaze behaviour to pick up information from relevant locations more efficiently than when this information was not available. While this body of work suggests that the sequence of events preceding a critical event influences anticipation, no published research to our knowledge has investigated whether the strength of this influence is affected by the number of events in the preceding sequence.

In addition to the preceding sequence of events, there is evidence to suggest that other sources of contextual information such as the positioning of the opponent prior to executing a skill can influence anticipation (Loffing & Hagemann, 2014). To identify the specific sources of postural information that facilitate anticipation, researchers have employed the spatial occlusion paradigm by artificially removing selected parts of the opponent's body/equipment such that their relevance as visual cues can be assessed using video simulations (e.g., Abernethy, 1990; Jackson & Mogan, 2007; Williams & Davids, 1998) and point-light or stick figure displays (e.g., Abernethy & Zawi, 2007; Abernethy et al., 2008; Huys et al., 2009). If there is a significant deterioration in accuracy when one part of the opponent's body or equipment is occluded, researchers can infer that this element is an important cue for accurate anticipation (e.g., the arm and racket in racket sports, Abernethy & Zawi, 2007; Abernethy et al., 2008; Shim, Carlton, & Kwon, 2006).

Similarly, some researchers have manipulated the information they present to participants to determine the sources of information facilitating expert pattern recognition and recall (e.g., Gorman, Abernethy, & Farrow, 2011; North et al., 2011; Williams, et al., 2012). In two experiments, Williams et al. (2012) manipulated videos of sequences from soccer matches such that they were presented in either still or dynamic format, and then presented videos in which central or peripheral elements were omitted from the dynamic display. They reported a decrement in pattern recognition for skilled soccer players in the still relative to the dynamic condition (see also Sebanz and Shiffrar [2009] for a similar finding in a deception detection task) and subsequently, when central elements were omitted from the display. Williams et al. (2012) suggested a key mechanism underpinning skilled pattern recognition in football is the effective extraction of motion information and that only the relative motions of a few key features (e.g., central midfielders and offensive players) is necessary for effective recognition of domain-specific patterns. However, some contradictory findings have been reported in pattern recall and decision-making tasks (Gorman et al., 2011; Gorman et al., 2013). Gorman et al., (2013) reported that pattern recall error was lower and decision making accuracy higher when viewing a still compared to a dynamic display involving basketball plays. This body of research is pertinent because it has been suggested that the ability to recognise and/or recall domain-specific patterns may act as an important precursor to effective anticipation (Cañal-Bruland & Williams, 2010; Gorman et al., 2012). What is particularly clear, however, is that the manipulation of representative test stimuli, is a useful way to determine the sources of information used by performers to make accurate judgments, which could ultimately lead to the identification of underlying mechanisms.

To date, those attempting to identify the sources of contextual information that contribute to skilled anticipation (e.g., Loffing & Hagemann, 2014; McRobert et al.,

2011) have done so with an emphasis on determining how this information interacts with postural cues. However, when placed under extreme time constraints, the time it takes for the action to be carried out may be so minimal that waiting for pertinent postural cues to become available is not feasible (Triolet et al., 2013). In such situations performers would be constrained to rely on contextual information alone to anticipate effectively. In this paper, we aim to provide a novel contribution by determining the extent to which specific sources of contextual information facilitate accurate anticipation independent of pertinent postural cues.

Study 3

Crognier and Féry (2005) examined whether tennis players anticipate more effectively in situations in which they can impose their game on the opponent compared to situations in which they have fewer possibilities to do so. To examine the effect of imposing one's game on an opponent (referred to as tactical initiative), experienced tennis players played points against an opponent in three conditions involving increasing levels of tactical initiative. The experiment was set up in such a way that sequence length was shortest in the low tactical initiative condition and longest in the high tactical initiative condition. Although the participants anticipated the direction of the opponent's shot most accurately following the longest sequences, because the opponent playing the passing shot was instructed to allow the participants to impose their game on him during these sequences, it is impossible to draw conclusions about whether this increase in accuracy was due to the additional contextual information picked up from the preceding shot sequences.

In this study, we examined whether contextual information can be picked up from the sequence of shots played prior to a critical event to facilitate anticipation. A secondary aim focused on determining whether the ability to use this information develops with increasing skill level. Finally, we investigated whether the length of the preceding sequence affects anticipation. We presented skilled and less-skilled tennis players with animations of sequences of shots played by players in real matches. In these animations, the bodies of the players were replaced by a cylinder and rackets were not visible (see Murphy et al., 2016), such that the observer was constrained to anticipate based on contextual information alone. To determine whether the preceding shot sequence provides contextual information which can be used to facilitate anticipation, we compared the ability of skilled and less-skilled participants to anticipate the intentions of an opponent when viewing trials that presented one, three or five shots prior to the same shot played by the opponent, occluded at racket-ball contact.

First, we hypothesised, based on the findings of Murphy et al. (2016), that for both groups, response accuracy would be significantly higher than chance. Second, based on the same research, we expected skilled participants to be more accurate than less-skilled participants. Third, to our knowledge, the only research that has provided any indication as to whether the sequence *length* preceding a critical event affects anticipation is that conducted by Crognier and Féry (2005). This aspect of the study was therefore exploratory in nature. Fourth, based on the findings of several previous research studies demonstrating that the judgments of skilled performers are affected by the presentation of contextual information over and beyond the presentation of postural information (e.g., Crognier & Féry, 2005; Farrow & Reid, 2012; Loffing & Hagemann, 2014), we hypothesised that skilled participants would anticipate more accurately when presented with the preceding shot sequence (i.e., three or five shot conditions) in addition to viewing the final occluded shot. We expected that the superior LTWM skills (Ericsson & Kintsch, 1995) possessed by the skilled participants would allow them to access potential relevant alternatives to the presented contextual information, allowing them to adjust their expectancies to make more accurate judgments than when this additional information was not presented. Conversely, we expected the accuracy of the less-skilled participants to be unaffected by the presentation of the preceding shot sequence.

Methods

Participants

Altogether, 12 skilled (M_{age} = 27.1, *SD* = 4.7) and 12 less-skilled (M_{age} = 24.7, SD = 5.3) male tennis players participated. Skilled and less-skilled participants had a mean of 20.2 (*SD* = 4.6) and 4.3 (*SD* = 3.6) years of tennis playing experience, respectively. Skilled participants held British Tennis ratings of 1.1 to 4.1, whereas less-skilled participants held ratings of 10.2 or did not hold a rating. British Tennis ratings range from 1.1 (highest) to 10.2 (lowest). Skilled participants reported having played a mean of 54.1 (*SD* = 24.1) matches per year, whereas less skilled players did not play competitively. One participant in the less-skilled group was left-handed and the rest were right-handed players. All participants had normal or corrected vision. Those with corrected vision wore glasses or contact lenses while participating. The research was carried out in line with the lead university's research ethics guidelines. Participants provided informed consent prior to taking part and knew that they could withdraw from testing at any time without consequence.

Test Stimuli

Player movement and ball trajectory data (Hawk-Eye Innovations Ltd., Basingstoke, UK) from professional tennis matches played at the AEGON Championships (2013) were used to create the test stimuli. The data were input into a rendering engine to generate animations of rallies which could then be viewed on VLC media player (VideoLAN, Paris, France). The purpose of using animations as opposed to video footage of rallies was to remove postural information from the players and the resulting racket movements such that participants would be constrained to anticipate based on contextual information alone. Any differences in accuracy between experimental conditions could therefore be attributed to the use of this information (for more details, see Murphy et al., 2016). The test stimuli were animations of real tennis rallies which displayed two players moving around the court playing a point, but which omitted the players' bodies and rackets such that they were depicted as a blue and a red cylinder and their rackets were not visible, while the ball was depicted as a yellow dot (see animated display condition in Figure 2.1). Pinnacle Studio 15 editing software (Pinnacle, Ottawa, Canada) was used to edit the animations to occlude at the opponent's racket-ball contact.

The criteria used for selecting the shot on which to occlude the footage was the same as that used by Murphy et al. (2016). Shots in which the receiving player was placed under extreme time constraints were selected from the database of rallies. In such conditions (e.g., when one player is attacking the other from inside the court or the distance between the two players is smaller than usual), players are constrained to respond earlier than usual to get to, and return, the opponent's shot effectively (Triolet et al., 2013). Furthermore, a minimum of six shots needed to be exchanged between the two players in the rally for it to be suitable for creating the longest sequence length condition (five preceding shots plus the final occluded shot). A total of 44 sequences of six shots were selected based on these criteria.

In an effort to ensure that we only used trials in which the shot sequence preceding the final occluded shot presented relevant contextual information, three experienced coaches independently viewed each of the 44 animated sequences that were occluded at the opponent's racket-ball contact on the sixth shot. All of the coaches had over 10 years of experience and had coached players of National and/or International level as well as having played at that level. For each of the 44 trials, each coach rated the extent to which the preceding shot sequence would contribute to successfully anticipating the outcome of the final occluded shot on a scale of 1 to 5 with 1 being "not at all" and 5 "extremely". Only sequences in which coaches reported an average rating greater than or equal to 4 were used as test stimuli, yielding a total of 23 trials. A similar procedure has been used in pattern recall and recognition research, where experienced coaches have identified structure in sequences of play to ensure that the footage being used is representative of structured gameplay (Gorman et al., 2012; North et al., 2009).

To determine the effect that increasing the number of shots in the sequence preceding the final occluded shot had on anticipation, participants viewed the 23 experimental trials in three conditions. Trials were edited to display one (short sequence length condition), three (medium), or five (long) shots in the sequence preceding the occluded shot, such that they viewed the same final occluded shot three times. The rationale for this approach was that it allowed for reliable comparison of anticipation response accuracy scores relative to three sequence lengths (see Figure 3.1). Altogether, 69 experimental trials were used (three sets of 23). Short, medium and long trials lasted an average of 1.38 (*SD* = .26), 4.18 (*SD* = .38), and 6.83 (*SD* = .55) seconds respectively. These trials were created from data from 10 matches involving 14 right-handed players, in various rounds of the tournament.

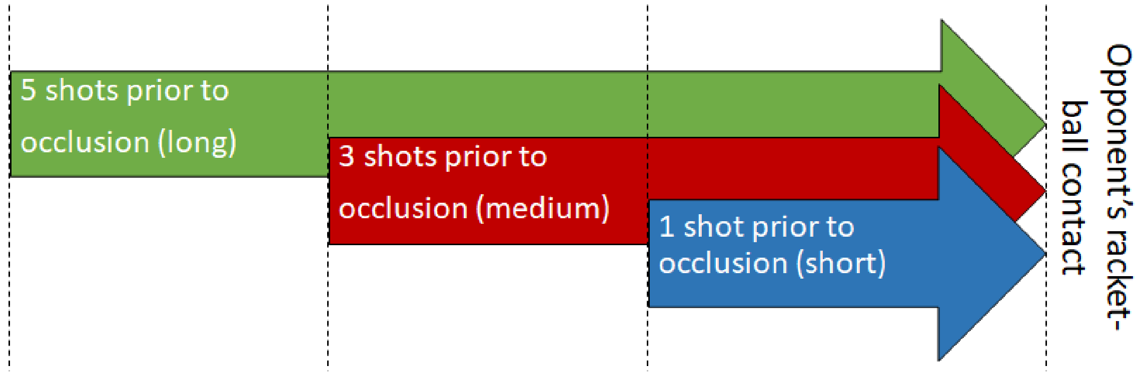


Figure 3.1. Representation of the number of shots played in each Sequence Length condition prior to the same shot occluded at the opponent's racket-ball contact.

Materials, Apparatus, and Set-Up

Test stimuli were projected on to a 4.1 × 2.3 m white projector screen (AV Stumpfl, Wallern, Austria) using a NEC PE401H projector (NEC, Tokyo, Japan). Participants held a racket in their hands as if they were about to play a point and stood 5 m from the screen which allowed for a viewing angle of 3.0° - 3.9° subtended by the opposing player. A similar viewing perspective has been used previously (Loffing et al., 2011; Murphy et al., 2016).

Procedure

Participants viewed 18 familiarisation and 69 experimental trials. Different rallies were used in the familiarisation trials than the experimental trials. Six sets of randomised experimental trials were created with two participants from each group viewing one of the six sets. Participants viewed three blocks of 23 trials with a one-minute break between blocks. This break was provided to mitigate against boredom or fatigue effects. Each of the 23 trials were presented three times. A yellow circle was displayed on a black screen for 2 seconds prior to the commencement of the trial to indicate where the ball would be once the trial started and a 6 second inter-trial interval was employed. In the experimental trials, the bounce location of the occluded shot landed deep (past the service line) on the left side (left of the centre line) of the court on eight trials, deep on the right side on eight trials, short (before the service line) on the left side on five trials and short on the right side on two trials. When trials were occluded, participants had been instructed to say aloud which quadrant of the court they anticipated the ball would bounce in (e.g., short-left), while additionally swinging their racket as if to return the upcoming shot. The racket was swung to make the task feel more realistic rather than to act as a dependent measure (cf., Roca, Williams, & Ford, 2014). The order in which participants carried out the verbal and physical response was not controlled. The primary researcher noted the verbal response. Accuracy was measured as the percentage of correct responses relative to actual final ball bounce location of the occluded shot. Participants did not receive feedback after any of the trials.

Data Analysis

One-sample *t*-tests were conducted to compare accuracy for the skilled and less-skilled participants compared with chance levels. A 2 × 3 (Group [skilled, less-skilled] × Sequence Length [short, medium, long]) MANOVA with repeated measures was conducted, with the percentage of correct depth, direction, and combined judgments serving as the dependent variables. The Greenhouse-Geisser correction was applied in the case of violations of sphericity. Partial eta squared (η_p^2) values are reported for effect size of main effects. The alpha level of statistical significance was set at .05. In the case of multiple *t*-tests, sequential Bonferroni was applied to control for family-wise error. Finally, pairwise comparisons were carried out in the case of significant interactions. Cohen's *d* is reported for effect size of these comparisons.

Results and Discussion

The mean (and standard error) depth, direction and combined response accuracy scores for skilled and less-skilled participants in short, medium and long sequence length conditions are presented in Figure 3.2. First, we hypothesised that both skilled and less-skilled participants would be more accurate than chance in all conditions, reaffirming previous findings indicating the importance of contextual information in anticipation. As expected, response accuracy scores were significantly greater than chance in all conditions (all $p < .01$). Participants were able to anticipate accurately based on contextual information alone regardless of skill level.

Second, consistent with our hypothesis that skilled participants would be more accurate than their less-skilled counterparts, a significant main effect of Group was observed, Wilks' Lambda = .37, $F(3, 20) = 11.53$, $p < .01$, $\eta_p^2 = .63$. This main effect was observed for depth, $F(1, 22) = 25.62$, $p < .01$, $\eta_p^2 = .54$, and combined judgments, $F(1, 22) = 30.55$, $p < .01$, $\eta_p^2 = .58$, but not for direction judgments, $F(1, 22) = 3.36$, $p = .08$, $\eta_p^2 = .13$. While a between-groups difference of 4.47% was observed for direction judgments, the observed differences and associated effect sizes for depth (12.44%) and combined (15.34%) judgments were larger. For depth judgments in particular, the relative movements and/or final positioning of the two players and the ball appears to provide contextual information which allows skilled participants to retrieve relevant alternatives from LTM to make more accurate depth judgments than less-skilled counterparts.

Third, the multivariate output revealed no significant effect of Sequence Length on response accuracy. However, because the only other study (Crognier & Féry, 2005) to our knowledge examining this issue previously in tennis revealed that direction accuracy specifically was increased when a sequence of shots was played prior to the final occluded shot, we examined the univariate output. We report a significant main effect of Sequence Length for direction, $F(2, 44) = 3.87$, $p = .03$, $\eta_p^2 = .15$, but not for depth, $F(2, 44) = .53$, $p = .60$, $\eta_p^2 = .02$, or combined judgments, $F(2, 44) = 3.05$, $p = .06$ $\eta_p^2 = .12$. After applying sequential Bonferroni with *p* values of .017, .025 and .05 respectively, direction accuracy significantly increased from short (*M* = 67.57%, *SE* = 1.72) to medium (*M* = 73.01%, *SE* = 1.74, *p* = .02, *d* = 0.64) but did not increase significantly from short to long (*M* = 72.65%, *SE* = 1.93, *p* = .03, *d* = 0.57) or from medium to long (*p* = .87, *d* = -0.04) trials. The medium effect sizes observed for differences between conditions in which the preceding shot sequence is presented and when it is not, suggest that contextual information can be picked up from the preceding shot sequence to facilitate anticipation. Moreover, given that accuracy increased from short to medium trials but not from medium to long trials, rather than a linear relationship existing between accuracy and sequence length, the important information appears to be contained in the shots immediately preceding the final occluded shot rather than earlier shots in the sequence.

The Skill × Sequence Length interaction was not significant at the multivariate or univariate levels; however, Figure 3.2 shows that skilled participants were more accurate in their direction judgments on medium (*M* = 75.72%, *SE* = 2.70; *p* = .02, *d* = 0.98) and long (*M* = 76.09%, *SE* = 2.36; $p < .01$, *d* = 1.13) compared with short trials (*M* = 68.12%, *SE* = 1.64). Accuracy did not increase significantly from medium to long trials (*p* = .46, *d* = 0.04). On the other hand, no significant differences in accuracy were observed between short (*M* = 67.03%, *SE* = 3.10) and medium (*M* = 70.29%, *SE* = 1.99, *p* = .13, *d* = 0.36), short and long (*M* = 69.20%, *SE* = 2.80, *p* = .28, *d* = 0.21), or medium and long trials (*p* = .33, *d* = -0.13) for the less-skilled group. The large effect sizes for the differences between short and medium or long trials for skilled participants and the small effect sizes for differences in the accuracy scores of less-skilled participants, at an exploratory level at least, indicate that skilled participants may be able to use contextual information picked up from the preceding shot sequence more effectively than less-skilled participants. We tentatively suggest that skilled participants were able to use the contextual information picked up from the shots immediately preceding the occluded shot to access relevant alternatives from LTM, adjusting their expectancies of likely event outcomes and increasing accuracy relative to when this information was not available.

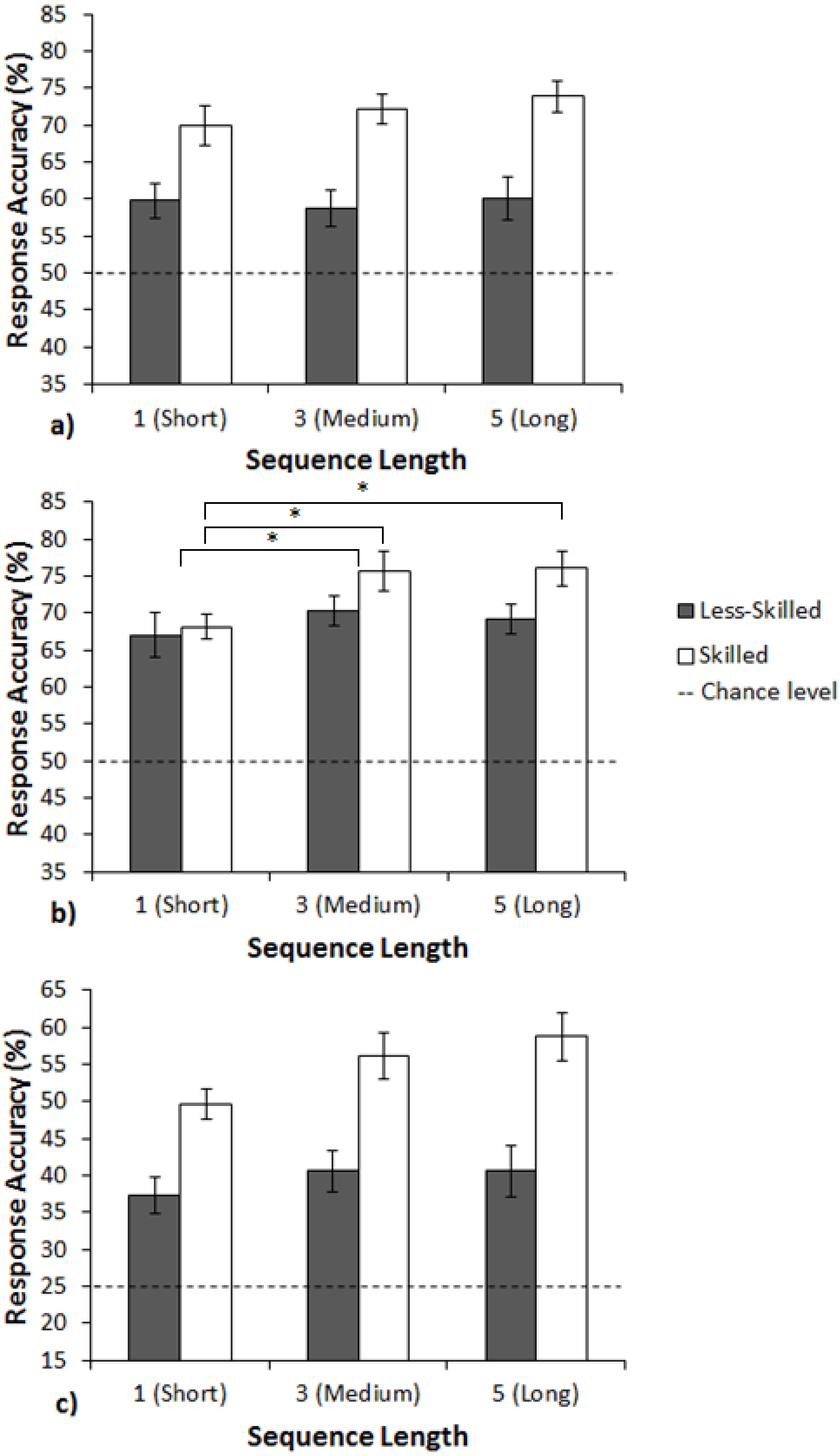


Figure 3.2. Mean (SE) depth (a), direction (b) and combined (c) response accuracy relative to sequence length across groups. *$p < .05$

In summary, in Study 3, we demonstrated that skilled participants in particular can use contextual information picked up from the preceding shot sequence to accurately anticipate and that the useful information appears to be contained in shots immediately preceding the critical event rather than in earlier shots. However, performers have been shown to rely on different sources of information to varying extents, dependent on the task constraints (Roca et al., 2013). It is therefore likely that in some instances contextual information other than that gleaned from the preceding shot sequence may be of greater utility. In Study 4, we therefore further investigate the sources of contextual information which can be used to facilitate anticipation independent of pertinent postural cues, particularly focusing on player and ball motion and positioning.

Study 4

In an initial attempt to determine the sources of contextual information facilitating anticipation independent of pertinent postural cues, Murphy et al. (2016) collected verbal reports from skilled and less-skilled participants when viewing the type of animations used in Study 3. Participants referred more often to the shot placement throughout the rally than anything else and skilled participants referred more often to court geometry (availability of spaces and angles between players) and shot type (e.g., volley, forehand) than less-skilled participants. Although verbal reports provide researchers with access to the conscious thoughts of participants when performing a task, non-verbal and non-propositional information may be difficult for participants to articulate, resulting in incomplete verbalisations (Ericsson & Simon, 1980). As an alternative, some researchers have collected confidence ratings from participants taking part in anticipation tasks to assess their awareness of the information they use to anticipate (Jackson & Mogan, 2007; Smeeton & Williams, 2012).

According to Rosenthal's (2000) higher-order thought hypothesis, if a performer has a higher-order thought about the mental state he/she is in, that state can be assumed to be a conscious mental state. Chan (1992) suggested that, in judgment tasks, high levels of accuracy associated with high confidence (the higher order thought) would indicate subjective awareness of the information being used to make accurate judgments, whereas low levels of confidence associated with high levels of accuracy would indicate a lack of subjective awareness. Confidence ratings, collected in conjunction with accuracy data can therefore provide an indication of the task-relevance of the presented information.

Jackson and Mogan (2007) assessed awareness of the sources of information tennis players were consciously using to inform anticipation of whether an opponent would serve to the left, middle, or right of the service box. The authors recorded the confidence levels of participants in their judgments following each trial. A decrement in performance when the ball was occluded compared to a no occlusion condition indicated that the ball (as it is tossed in the air prior to the serve being hit) is a useful source of information when anticipating serve direction. In studies of deception, researchers have shown that performers are more confident when viewing deceptive than non-deceptive actions of opponents (Jackson et al., 2006; Smeeton & Williams, 2012), indicating that performers consciously use misleading information intentionally presented by the opponent. In each of these studies as well as in other research where accuracy scores and confidence ratings have been recorded (e.g., Salmela & Fiorito, 1979; Tenenbaum et al., 1996) participants became more confident as more information was presented via reduced occlusion conditions.

In this study, we determined the extent to which player and ball motion and positioning provide contextual information which can facilitate anticipation and the sources of contextual information that tennis players consciously use when constrained to anticipate based on contextual information alone. We compared the accuracy and confidence levels of skilled and less-skilled tennis players when viewing animated footage of sequences of shots occluded on the sixth shot (the long condition in Study 3), which were viewed in a dynamic or still display condition, where the still display condition was presented as the final frame of the sequence at the opponent's racket-ball contact. These two display conditions were further presented in three conditions in which either the players, the ball, or both the players and the ball, were depicted.

First, based on the findings of Murphy et al. (2016), and other studies (e.g., Loffing & Hagemann, 2014; Loffing et al., 2016) proposing the importance of player positioning in providing contextual information, we hypothesised that participants would anticipate at higher than chance levels in conditions in which the players were depicted. We further hypothesised, based on the findings of the Study 3 and those of Murphy et al. (2016), that skilled participants would be more accurate than less-skilled participants. Second, based on research in which the spatial occlusion paradigm has been employed (e.g., Abernethy & Russell, 1987; Jackson & Mogan, 2007; Müller et al., 2010), we hypothesised that accuracy scores would be highest in the condition depicting both the players and the ball but that differences between this condition and other conditions would provide an indication of the relative importance of the players and the ball as independent information sources. Third, based on previous research which suggests that skilled tennis players use their domain-specific experience and knowledge to help them pick up and utilise contextual information from player positioning more effectively than less-skilled players (Loffing & Hagemann, 2014), we hypothesised that between-groups differences in accuracy would be more pronounced in conditions in which the players were visible than when only the ball was presented. Finally, based on the findings of Williams et al. (2012) and Sebanz and Shiffrar (2009), we hypothesised that accuracy scores would be higher in the dynamic than still display condition indicating the importance of motion information in the lead up to the event over and above mere positioning information at the moment of occlusion.

Additionally, we explored the relationship between accuracy and confidence relative to the information presented. We expected, based on the research of Chan (1992), a positive relationship between confidence and accuracy to indicate subjective awareness of the sources of information being used to anticipate accurately. We hypothesised, based on the findings of previous studies on anticipation in tennis (Jackson & Mogan, 2007; Tenenbaum et al., 1996), that no differences in judgment confidence would be observed between groups. We further hypothesised that confidence levels would be highest in the condition depicting both players and the ball as the most information would be available in that condition (Jackson & Mogan, 2007; Smeeton & Williams, 2012; Tenenbaum et al., 1996). Finally, we hypothesised that participants would be more confident in conditions in which more information was available for processing (e.g., when both players and ball are depicted or when viewing dynamic footage) compared to when less information is available (Jackson & Mogan, 2007; Salmela & Fiorito, 1979; Tenenbaum et al., 1996).

Methods

Participants

Altogether, 12 skilled (M_{age} = 25.8, *SD* = 3.7) and 12 less-skilled (M_{age} = 22.7, *SD* = 3.9) male tennis players with a mean of 20.6 (*SD* = 4.4) and 5.9 (*SD* = 4.9) years of tennis playing experience participated. Skilled participants held British Tennis ratings of between 1.1 and 4.1, whereas less-skilled participants held ratings of 10.2 or did not hold a rating. Skilled participants reported having played a mean of 43.2 (*SD* = 18.9) matches per year, whereas less-skilled participants did not play competitively. One participant in the less-skilled group and two in the skilled group were left-handed players and the rest were right-handed. All participants had normal or corrected vision and those with corrected vision wore glasses or contact lenses while participating. In total, eight of the skilled and seven of the less-skilled participants had taken part in Study 3 with the time between the two studies being approximately four to six months. The research was carried out in line with the lead university's research ethics guidelines, with participants providing informed consent prior to taking part and being aware that they could withdraw from testing any time without consequence.

Test Stimuli

The longest condition in Study 3 (five shots prior to the occluded shot) yielded the highest response accuracy scores and consequently, we used this length sequence in the current study. Altogether, 21 of the 23 sequences used in Study 3 were presented as experimental test stimuli. One trial was omitted because it yielded combined accuracy scores of 0% in long trials in Study 3. Another trial was excluded because the near player was not visible at the moment of occlusion as he was too far to the side of the court. The outcome of the first of these trials was short on the left side of the court, and was short on the right side for the latter. This yielded a remaining eight trials for which the outcome was deep on the left and deep on the right side of the court, four trials for which the outcome was short on the left and one trial for which the outcome was short on the right side.

Participants viewed each of the 21 trials either as moving videos (Dynamic display condition) or as a still image of the final frame of the video (Still display condition). Three presentation conditions were also employed: Full (both players and the ball were presented); Players (only the players were presented); and Ball (only the ball was presented). The Players and Ball conditions were created in the same way as described in Study 3, with either player movement or ball trajectory data omitted to create the required stimuli. In total, participants viewed each trial in six conditions (Dynamic Full, Dynamic Players, Dynamic Ball, Still Full, Still Players, and Still Ball). All dynamic trials displayed five shots prior to occlusion at the opponent's racket-ball contact on the sixth shot. Still trials were presented for the same amount of time as their corresponding dynamic trials (M = 6.82 s, SD = .55).

Materials, Apparatus, and Set-Up

The experimental set-up was the same as in Study 3.

Procedure

Participants viewed a total of 126 experimental (21 trials in each of the 6 conditions) and 18 familiarisation trials. Different rallies were used in the familiarisation trials than the experimental trials. Six sets of randomised trials were created with two participants from each group viewing one of the six sets. Participants viewed four blocks (two of 32, two of 31) of trials, viewing each of the 21 trials six times. A one-minute break was provided between blocks to mitigate against boredom or fatigue effects. Participants responded in the same way as in Study 3. In still trials, participants were required to wait for occlusion before responding. When viewing the familiarisation trials, participants were reminded that it was important not to respond until the point of occlusion. After verbally predicting the outcome of the opponent's shot, participants then verbally rated how confident they were in their combined judgment on a scale of 1 to 5, with 1 being not at all confident, and 5 being extremely confident. Participants did not receive feedback after any of the trials. An inter-trial interval of six seconds was employed.

Data Analysis

Response Accuracy

One-sample *t*-tests were conducted to compare depth, direction, and combined judgments to chance levels in each presentation and display condition. Since the number of dependent variables was greater than the number of participants in each group, rather than conducting a MANOVA, we ran a 2 (Group [skilled, less-skilled]) × 2 (Display [Dynamic, Still]) × 3 (Presentation [Full, Players, Ball]) ANOVA for each of depth, direction, and combined judgments.

Confidence Ratings

First, to determine whether there was a correlation between accuracy and confidence on the 21 individual trials, we calculated Pearson's moment correlation coefficient in each of the six conditions for skilled and less-skilled participants. Second, a 2 (Group) × 2 (Display) × 3 (Presentation) ANOVA was conducted for confidence ratings of combined judgments.

Partial eta squared (η_p^2) values are reported throughout for effect size of main effects. In the case of violations of sphericity, the Greenhouse-Geisser correction was applied. The alpha level of statistical significance was set at .05. Sequential Bonferroni adjustments were applied in the case of multiple pairwise comparisons to adjust for family-wise error. Finally, pairwise comparisons were conducted in the case of significant interactions and main effects. Cohen's *d* is reported for effect size of these comparisons.

Results and Discussion

Response Accuracy

The mean depth, direction, and combined response accuracy (and standard error) of skilled and less-skilled participants are presented in Figure 3.3. We hypothesised, based on previous research suggesting the potential importance of player positioning as a source of contextual information (e.g., Loffing & Hagemann, 2014; Murphy et al., 2016), that participants would be more accurate than chance in the two presentation conditions depicting the players. One-sample *t*-tests revealed that skilled participants were significantly more accurate than chance for depth, direction, and combined judgments in all presentation conditions in both dynamic and still format (all $p < .01$), except direction judgments in the Still Ball condition, while less-skilled participants were more accurate than chance in all presentation conditions in dynamic and still format (all $p < .05$), except for direction and combined judgments in the Still Ball condition. This finding is further confirmation of the contribution of contextual information to accurate anticipation. While Murphy et al. (2016) demonstrated that contextual information can be used to anticipate effectively, independent of access to pertinent postural cues, these findings indicate that enough contextual information can be picked up solely from the motions and final positions of the players or the ball (although the final position of the ball does not appear sufficient for making direction judgments) to facilitate anticipation.

As in Study 3, and in support of Murphy et al. (2016), a significant main effect of Group was observed for depth, $F(1, 22) = 15.98$, $p < .01$, $\eta_p^2 = .42$ and combined judgments, $F(1, 22) = 24.55$, $p < .01$, $\eta_p^2 = .53$ but not direction judgments, $F(1, 22) = 3.73$, $p = .07$, $\eta_p^2 = .15$. Larger between groups differences of 11.38% and 12.77% were observed for depth and combined judgments, in comparison to direction judgments (4.56%).

Second, we hypothesised, based on previous research employing the spatial occlusion paradigm (e.g., Abernethy & Russell, 1987; Jackson & Mogan, 2007), that accuracy would be highest in the Full Presentation condition. A significant main effect of Presentation was observed for depth, $F(2, 44) = 4.29$, $p = .02$, $\eta_p^2 = .16$, direction, $F(2, 44) = 70.88$, $p < .01$, $\eta_p^2 = .76$, and combined judgments, $F(2, 44) = 33.71$, $p < .01$, $\eta_p^2 = .61$. The effect sizes imply a larger effect of Presentation condition for direction and combined than depth judgments. Combined accuracy scores were lower in the Ball (*M* = 35.71%, *SE* = 1.14), compared to the Players (*M* = 48.31%, *SE* = 2.30, *p* < .01, *d* = 0.93) and Full conditions (*M* = 51.39%, *SE* = 1.58, *p* < .01, *d* = 1.20), with accuracy in the Players and Full conditions not differing significantly (*p* = .11, *d* = 0.20). The decrement in performance when the players were omitted from the display is indicative of their importance as an information source. A similar pattern was observed for direction (Ball: *M* = 54.56%, *SE* = 1.26; Players: *M* = 72.82, *SE* = 1.82; Full: *M* = 71.73, *SE* = 1.50) with significant differences observed between the Full and the Ball conditions (*p* < .01, *d* = 1.29) and between the Players and Ball conditions (*p* < .01, *d* = 1.42) but not the Full and Players conditions (*p* = .42, *d* = -0.09). However, mean differences were much smaller for depth (Ball: *M* = 68.25%, *SE* = 1.62; Players: *M* = 66.17, *SE* = 1.92; Full: *M* = 70.54, *SE* = 1.40) for which comparatively high scores were observed when only the ball was visible. Accuracy scores were significantly higher in the Full than the Players condition (*p* < .01, *d* = 0.38). No significant differences were observed between the Full and the Ball (*p* = .10, *d* = 0.21) or the Ball and Players conditions (*p* = .23, *d* = 0.18). In line with our hypothesis, overall accuracy was highest when both the players and the ball were depicted suggesting these sources are most useful when presented in tandem. Nevertheless, more pronounced decrements in performance when the players were omitted from the display indicate that, particularly for direction judgments, they are a more important source of contextual information than the ball.

A significant Display × Presentation interaction was observed for direction, $F(2, 44) = 15.86$, $p < .01$, $\eta_p^2 = .42$, and combined judgments, $F(2, 44) = 7.78$, $p < .01$, $\eta_p^2 = .26$, but not depth judgments, $F(2, 44) = .55$, $p = .58$, $\eta_p^2 = .02$. Follow-up pairwise comparisons revealed that the direction and combined differences between Still and Dynamic display conditions were significant for the Ball condition (direction: $p < .01$, $d = 1.73$, combined: $p < .01$, $d = 1.20$), but not for the Players or Full conditions. We further investigated the interaction separately for the Dynamic and Still display conditions. In the Dynamic condition a main effect of Presentation was significant for depth, $F(2, 44) = 3.60$, $p = .04$, $\eta_p^2 = .14$, direction, $F(2, 44) = 8.33$, $p < .01$, $\eta_p^2 = .28$, and combined judgments, $F(2, 44) = 7.81$, $p < .01$, $\eta_p^2 = .26$ but no significant interactions were observed. The direction accuracy scores were higher in the Dynamic Full ($M = 71.83$, $SE = 1.87$, $p < .01$, $d = .79$) and Dynamic Players ($M = 71.43$, $SE = 2.01$, $p < .01$, $d = .75$) conditions than in the Dynamic Ball ($M = 63.49$, $SE = 2.39$) condition. The combined accuracy scores were higher in the Dynamic Full ($M = 51.19$, $SE = 2.47$) than the Dynamic Ball condition only ($M = 41.47$, $SE = 2.10$, $p < .01$, $d = .87$). No significant differences were observed for depth judgments. In the Still condition a main effect of Presentation was significant for direction, $F(2, 44) = 59.08$, $p < .01$, $\eta_p^2 = .73$ and combined judgments, $F(2, 44) = 27.52$, $p < .01$, $\eta_p^2 = .56$ but not depth, $F(2, 44) = 49.13$, $p = .46$, $\eta_p^2 = .04$ and no significant interactions were observed. The accuracy scores for direction were higher in the Still Full (M = 71.63, SE = 3.24, p < .01, d = 2.02) and Still Players (M = 74.21, SE = 2.64, p < .01, d = 2.42) conditions than in the Still Ball (M = 45.64, SE = 1.87) condition. Also, the combined accuracy scores were higher in the Still Full (M = 51.59, SE = 3.22, p < .01, d = 1.58) and Still Players (M = 50.40, SE = 3.37, p < .01, d = 1.43) conditions than in the Still Ball (M = 29.96, SE = 1.80) condition. These findings suggest that, when making direction judgments in particular, contextual information picked up from the movements and final positioning of the players facilitates anticipation more so than the movement and final positioning of the ball.

We hypothesised that between groups differences would be stronger when the players were depicted than when only the ball was depicted. However, the Group × Presentation interaction was not significant for depth, $F(2, 44) = 1.65$, $p = .20$, $\eta_p^2 = .07$, direction, $F(2, 44) = 1.14$, $p = .33$, $\eta_p^2 = .05$, or combined, $F(2, 44) = 3.04$, $p = .06$, $\eta_p^2 =$ .12, judgments. The increase in combined accuracy from the Ball (Skilled: M = 39.29%, SE = 1.61; Less-skilled: M = 32.14, SE = 1.61) to the Players (Skilled: M = 55.56%, SE = 3.25; Less-skilled: M = 41.07, SE = 3.25) and Full (Skilled: M = 59.72%, SE = 2.23; Less-skilled: M = 43.06, SE = 2.23) conditions was greater for skilled than less-skilled participants. These data, however, do not conclusively imply that the players provide contextual information that skilled participants can use to anticipate more accurately than less-skilled participants.

Third, based on the findings of Williams et al. (2012) and Sebanz and Shiffrar (2009), we hypothesised that accuracy scores would be higher in the Dynamic than the Still display condition. In contrast to our hypothesis, the main effect of Display was not significant for depth, $F(1, 22) = .28$, $p = .60$, $\eta_p^2 = .01$, direction, $F(1, 22) = 3.23$, $p = .09$, $\eta_p^2 = .13$, or combined judgments, $F(1, 22) = .85$, $p = .37$, $\eta_p^2 = .04$. This finding was surprising given that a main effect of Sequence Length was observed for direction judgments in Study 3. One would therefore expect that in this study participants would be more accurate when the preceding shot sequence was presented (in the Dynamic Display condition) than when it was not (in the Still Display condition). The final positioning of the players and the ball at racket-ball contact (particularly when presented together) potentially yield as much information as when the motion of the players and the ball in the lead up to racket-ball contact is also available. No other significant main effects or interactions were observed.

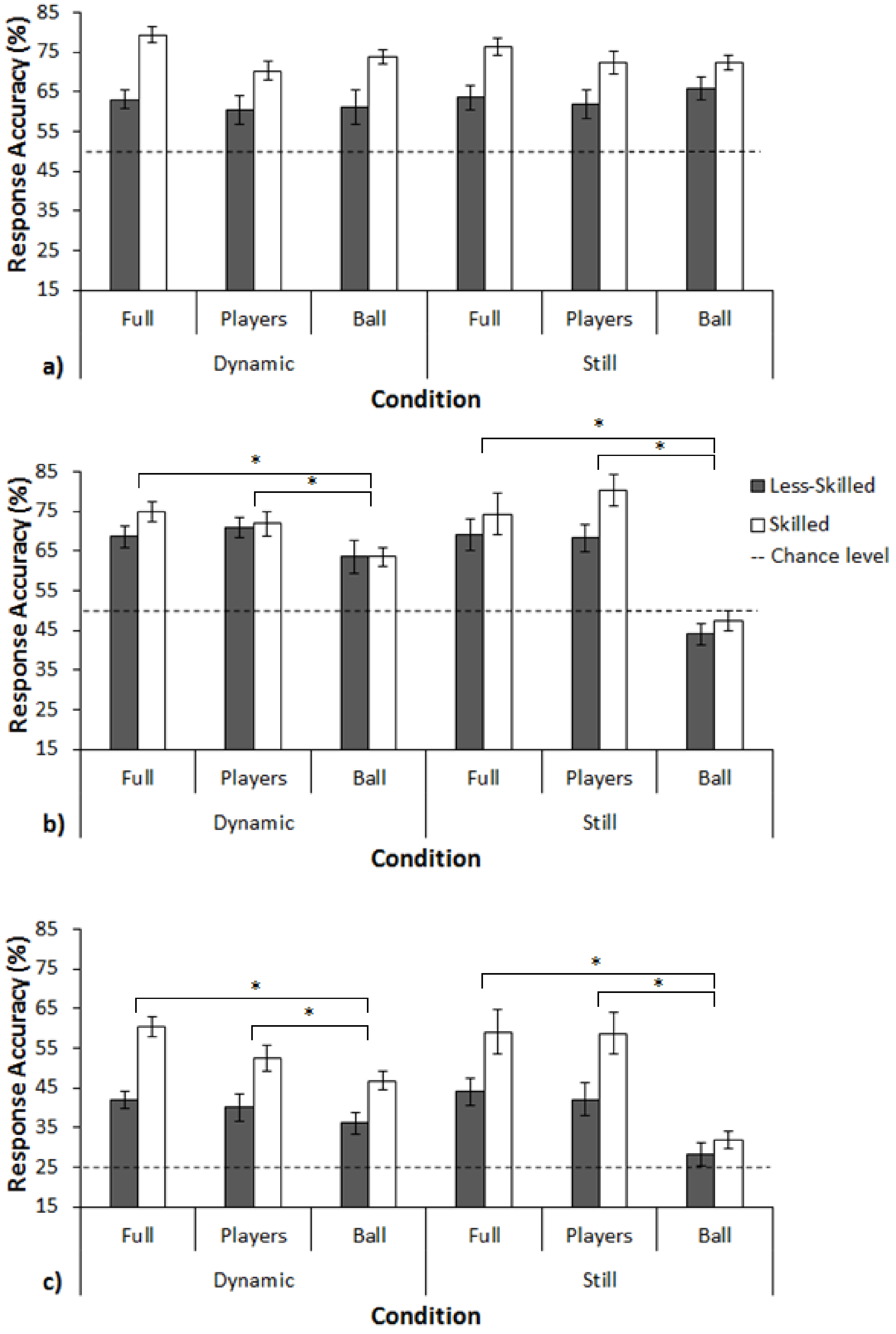


Figure 3.3. Mean (SE) depth (a), direction (b) and combined (c) response accuracy in the six display and presentation conditions across groups. *$p < .05$

Solution Probabilities

To determine the relationship between accuracy and confidence levels on the 21 individual trials, and thus determine the extent to which participants were aware of the information they were using to inform their judgments (Chan, 1992), we calculated Pearson's moment correlation coefficients in each of the 6 conditions for skilled and less-skilled participants. There was a strong significant correlation ($r = .577$, $p < .01$) between combined accuracy and confidence in the Dynamic Full condition for skilled participants only. Because the skilled participants were highly confident in their more accurate judgments and less confident in their less accurate judgments in this condition only, we suggest that they consciously use a combination of player and ball movements when making these judgments (Chan, 1992). Skilled participants were also more accurate than less-skilled participants when making judgments in this condition ($p < .01$, $d = 2.31$). It therefore appears that both the motion of the players and the ball in the lead up to the opponent's racket-ball contact are required for skilled performers to be aware of the information they should attend to in order to anticipate highly accurately.

Confidence Ratings

The mean confidence levels (and standard error) of skilled and less-skilled participants for each display and presentation condition are presented in Figure 3.4. First, based on the findings of Jackson and Mogan (2007), we hypothesised that confidence would not differ across the two groups. A 2 (Group) × 2 (Display) × 3 (Condition) ANOVA revealed that the main effect of Group was non-significant, $F(1, 22) = 3.77$, $p = .07$, $\eta_p^2 = .15$. The large effect size reflected skilled participants being more confident ($M = 2.84$, $SE = .15$) overall than their less-skilled counterparts ($M = 2.44$, $SE = .15$). Although not statistically significant, the direction of the effect is in contrast with the findings of both Tenenbaum et al. (1996) and Jackson and Mogan (2007) who reported lower levels or levels of confidence that did not differ respectively in skilled compared to less-skilled tennis players when judging the direction of tennis serves. However, the higher confidence ratings of the skilled group in this study reflect the overall higher accuracy scores they made in comparison to the less-skilled participants.

Second, we hypothesised that participants would be more confident in the dynamic than the still display condition. A significant main effect of Display, $F(1, 22) = 18.12$, $p < .01$, $\eta_p^2 = .45$, was observed. The confidence ratings were higher when viewing the Dynamic display ($M = 2.83$, $SE = .11$) than the Still display ($M = 2.45$, $SE = .11$). Although the expected significant effect of Display was not observed for accuracy, participants appear to consider player and ball information presented in a dynamic manner to be more useful to informing their judgments than just the final positioning of these elements.

Third, we hypothesised that participants would be most confident when viewing the Full display conditions. A significant main effect of Presentation condition was observed, $F(2, 44) = 43.46$, $p < .01$, $\eta_p^2 = .66$. Participants were more confident ($p < .01$) in the Full condition ($M = 3.01$, $SE = .12$) than in the Players ($M = 2.48$, $SE = .12$) and Ball conditions ($M = 2.43$, $SE = .10$). This supports the findings of Jackson and Mogan (2007), who found that participants were more confident when anticipating serves in conditions of no occlusion in comparison to when certain parts of the opponent’s body or equipment were occluded (see also Tenenbaum et al., 1996).

Finally, a significant Display × Presentation interaction was observed, $F(1.47, 32.4) = 25.23$, $p < .01$, $\eta_p^2 = .53$. Follow-up pairwise comparisons revealed that participants were more confident when viewing the Dynamic Ball ($M = 2.82$, $SE = .12$) than the Still Ball condition ($M = 2.05$, $SE = .13$, $p < .01$, $d = 1.23$) and when viewing the Dynamic

Full (M = 3.13, SE = .12) than the Still Full condition (M = 2.89, SE = .13, p = .01, d = 0.38), although the effect size was much smaller for this difference. The difference in confidence between the Dynamic Players (M = 2.54, SE = .13) and Still Players (M = 2.42, SE = .13) conditions was non-significant. In conjunction with the accuracy findings in the Still Ball condition, the large effect size observed between Dynamic and Still Ball conditions further indicates that participants do not consider final ball position to be a useful source of information on its own for making accurate anticipation judgments. Conversely, participants appear to find the final positioning of the two players to be just as useful as when the motion of the two players is presented throughout the rally. No other significant main effects or interactions were observed.

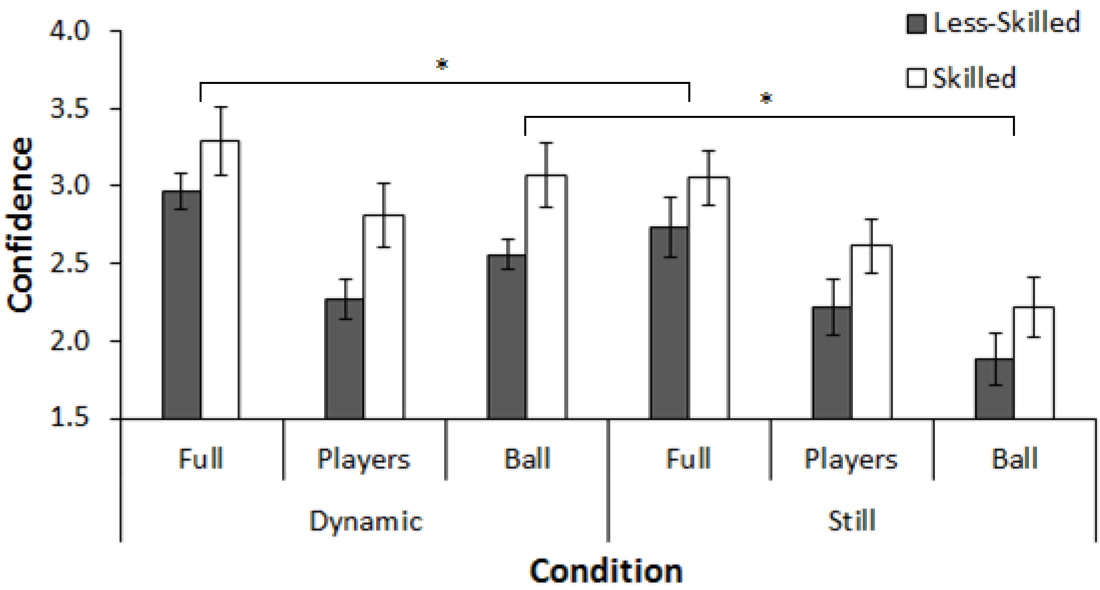


Figure 3.4. Mean (SE) confidence ratings of skilled and less-skilled participants in the six display and presentation conditions. *$p < .05$

General Discussion

We investigated the extent to which specific sources of contextual information (shot sequencing, player and ball motion and positioning) facilitate anticipation. The ability to use contextual information to anticipate effectively may be crucial, particularly when constrained to anticipate in advance of pertinent postural cues becoming available due to extreme time constraints. In Study 3, we examined whether the shot sequence preceding the to-be-anticipated shot could be used to facilitate anticipation by presenting skilled and less-skilled participants with sequences of shots of varying length. In Study 4, we investigated whether player and ball motion and positioning could be used to facilitate accurate anticipation by presenting footage which depicted the players, the ball or both in dynamic or still form, as well as investigating participant awareness of the information used to respond, reflected in confidence level.

In line with previous findings demonstrating that performers can use contextual information picked up from the preceding sequence of events (e.g., Loffing et al., 2015; Milazzo et al., 2015), participants became more accurate in their direction judgments when presented with the shot sequence preceding the occluded shot. This finding extends previous research by demonstrating that the preceding shot sequence provides contextual information which can be used to accurately anticipate the direction of an opponent's shot independent of postural information. Moreover, we observed that the important contextual information picked up from the preceding shot sequence appears to be contained in the shots immediately preceding the critical event. Intuitively, at least, this seems to make sense, in that in dynamic sports like tennis, the situation can change drastically from one shot to the next. These findings have implications for the design of testing and training protocols as well as for the level of detail that should be reported by researchers about the test stimuli used to conduct studies. Previously, researchers have considered it sufficient to merely report the duration of trials prior to occlusion (e.g., North et al., 2011; Gorman et al., 2013; Ward et al., 2013). We suggest that in future, researchers should also report the number of actions or events in the preceding sequence such that the extent to which this information may contribute to the judgments being made can be inferred.

While we expected that skilled participants would be able to use contextual information picked up from the preceding shot sequence to anticipate more effectively than less-skilled counterparts, the Group × Sequence Length interaction did not reach statistical significance. We suggest that the sequential patterns emerging from the preceding shots were not complex enough to clearly differentiate between skill groups. Loffing et al. (2015) found that task complexity affected whether the judgments of less-skilled participants were influenced by sequential patterns in a volleyball anticipation task. Initially, only skilled volleyball players were influenced by sequential patterns, whereas when the task difficulty was reduced, the less-skilled players were also influenced. As a result of the vast amount of experience and practice accumulated, skilled performers have built up large knowledge bases, which can be drawn upon to adjust their expectancies of potential event outcomes in domain-specific situations. It is likely that in addition to general patterns of play which potentially apply in many sports, more complex domain-specific patterns of play exist (McGarry & Franks, 1996) which require domain-specific knowledge to be detected and subsequently used to facilitate anticipation. It is possible that the test stimuli used in this study included more simple rather than complex patterns, decreasing the likelihood of skill differences being observed.

The contextual information gleaned from the players was observed to be more useful than the ball for making accurate anticipation judgments. Combined accuracy was lowest in the Ball condition with no differences being observed in combined accuracy between the Full and Players conditions. The increase in accuracy as a result of including the ball in the display in addition to the players was therefore minimal. Loffing et al. (2011) reported similar findings when ball flight information was presented in addition to the opponent's body movements and court positioning. Although the already high direction accuracy scores increased when ball flight information was made available, this increase was not statistically significant. It appears that while the ball contributes to accurate anticipation, it is not an essential information source. Conversely, the relative movements and/or positioning of the players (see also Loffing & Hagemann, 2014) appear to provide highly important information without which severe decrements in anticipation occur.

Although the ball was shown not to be as useful an information source as the players, participants were nevertheless able to pick up some useful information from it. Specifically, accuracy significantly increased from the Still to the Dynamic display condition when only the ball was presented. In contrast, no differences in display condition were found when only the players or both the players and the ball were presented. While it appears that as much useful contextual information may be picked up from the final position of the players as when the preceding movements are also available, the useful contextual information picked up from the ball comes from its flight. Moreover, given that direction rather than depth accuracy increased when the preceding shot sequence was presented in Study 3 and it is direction accuracy, again, which increases when the motion of the ball is presented rather than just its final position, we tentatively suggest that it is this information that is picked up from the ball flight when its motion is presented.

The somewhat lower accuracy in the Dynamic Ball in comparison to the Dynamic Full condition nevertheless suggests that participants integrate all available sources of relevant information to make accurate judgments. The confidence data support this notion, in that confidence levels were highest when both the players and the ball were presented. Moreover, the positive correlation between confidence ratings and accuracy for the skilled participants in the Dynamic Full condition suggests that only when both the players and the ball are depicted are they aware of the information they are using to anticipate effectively. Ward et al. (2013) and Belling et al. (2015a) suggest, based on Long Term Working Memory theory (Ericsson & Kintsch, 1995), that when presented with a domain-specific situation, skilled performers have access to more task-relevant and fewer task-irrelevant options than less-skilled performers, which ultimately results in more accurate judgments. The Dynamic Full condition most closely mimics the conditions in which the skilled participants in this study would have built up large amounts of experience and practice. It is therefore possible that only when both the motion of the players and the ball are presented can skilled participants consciously attend to and use this information in a manner in which it can be associated with an appropriate retrieval cue to facilitate access to task-relevant options from LTM.

Because direction accuracy was higher when the preceding shot sequence was presented in Study 3 than when it was not, we expected a similar effect when participants viewed dynamic animations containing the preceding shot sequence compared to when they viewed only a still image in Study 4. In contrast to our hypothesis, and the findings of Williams et al. (2012), this effect was not significant. Gorman et al. (2013) observed that performance levels were higher in a static than a dynamic basketball pattern recall and decision making task. The authors suggested that although dynamic sequences contain more information (via the build-up of actions in the preceding sequence), a combination of the shorter viewing time of the final frame of the dynamic sequences (.03 seconds in our study) in comparison to when viewing the still images (approximately 7 seconds in our study), and the complex nature of the dynamic sequences may have had a detrimental effect on performance. The duration of the still trials in Study 4 is therefore a potential limitation in our approach. However, although higher confidence levels when viewing dynamic sequences rather than still images indicate that dynamic sequences may be perceived to contain more useful information than a still image of the critical event, if these still images are presented for a long enough period of time, useful contextual information can be picked up from the positioning of the players to anticipate as accurately as if more information is presented in a dynamic manner. The practical significance of this effect is questionable because in real-world dynamic tasks this information is usually only presented for a very a short period of time. Perhaps the message is that in dynamic tasks the final positions of the various elements in the environment contain useful information which, if the rapid extraction of this information can be trained, could facilitate anticipation.

Another potential limitation of the study is that the laboratory setting and response modality we employed do not directly correspond with what would be found in a real-world setting. The verbal response used, decouples perception and action and therefore the extent to which these findings would transfer to a real-world setting is not clear (Dicks et al., 2010; van der Kamp, Rivas, van Doorn, & Savelsbergh, 2008). Additionally, when playing tennis, players would have a first person perspective and therefore only see one player (the opponent) rather than two players (as in our stimuli). Whilst numerous other researchers have successfully employed a similar viewing perspective or employed a similar methodological approach (e.g., Gorman et al., 2013; Vaeyens, et al., 2007; Williams & Davids, 1998; Williams et al., 2012) in studies on anticipation, decision making and pattern perception, we recommend that in future, researchers continue to create experimental set-ups which more closely represent the real-world environment (e.g., Ranganathan & Carlton, 2007; Runswick et al., 2017). Nevertheless, we do believe that in some instances, doing so may not be possible, or indeed the best approach to adopt. For example, given that our aim in this paper was to determine the extent to which specific sources of contextual information facilitate anticipation independent of pertinent postural cues, it is likely that technological limitations would have made eliminating such cues in a field-based study impossible. Moreover, in our current approach, depicting both players was necessary to determine the importance of player movement and positioning in particular. Additionally, differences across skill groups were observed in this paper, providing a modicum of construct validity for the approach.

In sum, we examined the extent to which specific sources of contextual information could be used by skilled and less-skilled tennis players to make accurate judgments when constrained to anticipate the outcome of an opponent's shot independent of pertinent postural cues. We presented novel findings indicating that when presented with the shot sequence preceding the to-be-anticipated shot, direction but not depth accuracy was positively affected. We further demonstrated that the relative motion and positioning of the players appear to provide more useful contextual information than the ball flight and that only when both player and ball motion is available in the lead up to the critical event are skilled performers aware of the information they use to inform their judgments. It appears that rather than acting independently, all of the sources of contextual information which would normally be available prior to pertinent postural cues becoming available interact, and through experience and practice can be utilised to effectively facilitate highly accurate anticipation judgments in skilled performers.

Chapter 4

Informational constraints, option generation and anticipation

Abstract

When anticipating an opponent's intentions in dynamic, temporally-constrained tasks, skilled performers are thought to initially rely on contextual information with pertinent postural cues becoming available closer to the moment of the critical event (Müller & Abernethy, 2012). Option generation paradigms can provide an insight into the cognitive mechanisms underpinning skilled anticipation. 12 skilled and 14 less-skilled tennis players completed an option generation task when presented with rallies from real matches in two display conditions. Rallies were presented as videos or as animations, which were edited in such a way that participants either had access to contextual and postural information (videos) or solely contextual information (animation; e.g., player positioning, shot sequencing). Skilled participants were more accurate than less-skilled participants in both display conditions. Participants generated less options in the video compared with the animated condition. Moreover, skilled participants generated more task-relevant and fewer task-irrelevant options than less-skilled participants, with this effect being stronger in the animated than the video condition. The number of options generated was negatively related to performance in the video condition only. In dynamic, temporally-constrained tasks, performers adapt their option generation strategy depending on the information available. In keeping with Long Term Working Memory theory (Ericsson & Kintsch, 1995), when constrained to anticipate based on contextual information alone, effective anticipation is underpinned by being able to access both the likely outcome and potential relevant alternatives. Moreover, when pertinent postural cues become available, option generation strategies consistent with the Take The First heuristic model may be optimal (Johnson & Raab, 2003). Implications for performance and training are discussed.

Introduction

In dynamic, fast ball sports such as tennis, the information available to performers when trying to anticipate changes on a moment-to-moment basis (Triolet et al., 2013). It is therefore not surprising that expert performers have developed the skills required to use postural cues (e.g., Müller et al., 2006; Ward et al., 2002) and to pick up contextual information such as shot sequencing and player positioning (e.g., Crognier & Féry, 2005; Farrow & Reid, 2012; Loffing & Hagemann, 2014) in order to anticipate quickly and accurately. The extent to which these two types of information facilitate accurate anticipation appears to vary as the critical event approaches (i.e., racket-ball contact by an opponent), with contextual information being available prior to and during an opponent's movement pattern and pertinent postural cues arising later in the action as the opponent shapes up to play the decisive stroke (Buckolz et al., 1988; Farrow & Abernethy, 2015; Müller & Abernethy, 2012). However, while our knowledge of how skilled performers use postural cues to anticipate is well developed, our understanding of how contextual information is used to facilitate the process remains limited (Cañal-Bruland & Mann, 2015).

In fast ball sports like tennis it is not uncommon for the time taken to process information and initiate a response to exceed the time available to the player prior to ball arrival (Williams et al., 1999). Triolet et al. (2013) used video-based analyses to show that, in professional tennis, players adapt their behaviour to deal with this time constraint by using different sources of information to inform their judgments as the rally develops. The researchers inferred the frequency of anticipation behaviours based on the timing of each player's lateral movements relative to the opponent striking the ball. In favourable or neutral conditions (e.g., when the opponent was out of position or when rallying from behind the baseline), responses appeared to be largely based on ball flight information as players could afford the time to wait for this information to become available. However, in unfavourable conditions (e.g., when the opponent was inside the court area and the receiving player was out of position) players more often than not began to respond well in advance of the opponent striking the ball, implying that they were anticipating based either on contextual information (associated with the earliest occurring movements) or a combination of contextual and later arising postural information (associated with later occurring movements prior to racket-ball contact). Moreover, the accuracy of these early-occurring anticipation behaviours was much higher than chance level, suggesting that contextual information may be used to guide anticipation judgments. The authors concluded that highly skilled performers use different types of information to anticipate effectively depending on the constraints present at that time.

In order to determine how athletes use postural information to anticipate, skilled and less-skilled performers have been asked to make judgments based on viewing footage of an opponent carrying out an action in which the visual display was manipulated/occluded (e.g., Müller et al., 2010; Williams & Burwitz, 1993) and/or while process-tracing measures such as gaze data were collected (e.g., McRobert et al., 2009, Savelsbergh et al., 2002). Skilled performers have been shown to pick up and utilise pertinent postural cues to anticipate more effectively than less-skilled counterparts (Mann et al., 2007). These cues appear to become available up to a few hundred milliseconds prior to the critical event, before which the postural information picked up from the opponent's body movements does not facilitate anticipation. Although in recent years researchers have examined how skilled performers use earlier occurring contextual information to anticipate (e.g., McRobert et al., 2011; Milazzo et al., 2015; Murphy et al., 2016), the majority of published work has examined *whether* rather than *how* performers use contextual information to anticipate (e.g., Abernethy et al., 2001; Crognier & Féry, 2005; Farrow & Reid, 2012; Loffing & Hagemann, 2014). Since the information performers have available to them develops over time as the critical event (e.g., racket-ball contact) approaches (Triolet et al., 2013), research is required to examine the mechanisms underpinning skilled anticipation in such instances when players are constrained to anticipate based on contextual information alone compared with instances when pertinent postural cues have also become available.

A common approach has been to present participants with potential alternatives from which to choose what the opponent is most likely to do next (e.g., Bourne, Bennett, Smeeton, Hayes, & Williams, 2013; Loffing et al., 2015; Roca et al., 2011). However, in real-world situations, performers must assess the situation and generate potential alternative courses of action prior to choosing what is deemed most likely to happen. Although this process would appear critical in real-world situations, very few researchers have employed option generation paradigms when examining anticipation in sport (for exceptions, see Belling et al., 2015a, 2015b; Klein & Peio, 1989; Ward, et al., 2013) or other domains (Ward et al., 2011). Nevertheless, to develop a more complete understanding of how expert performers use information from the environment to anticipate the opponent's intentions, examining the option generation strategies that underpin superior anticipation seems pertinent.

Klein and Peio (1989) used an option generation paradigm to investigate skilled anticipation in chess, suggesting that the strategies employed were consistent with the Recognition Primed Decision (RPD) model (e.g., Klein, 1993; Klein et al., 1986). The RPD model suggests that skilled decision making is associated with the generation of few options from which a feasible response can be chosen. In the simplest cases, skilled performers recognise the situation and carry out the most feasible response, whereas in more complex cases, skilled performers generate options sequentially, only generating additional options if the earlier option is deemed unsuitable. In support of the RPD model, Klein and Peio (1989) observed that in addition to anticipating the opponent's next move more accurately than novices, there was a trend for skilled chess players to generate fewer options per trial than less-skilled players. Additionally, the skilled participants were more likely to generate the actual outcome as their first option.

Johnson and Raab's (2003) Take The First (TTF) heuristic model shares some concepts with the RPD model. The TTF heuristic model suggests that through extended domain-specific experience, associations form between situations and options with the association strengthening if the option is repeatedly chosen. In subsequent similar situations, more strongly associated options are generated first and skilled performers take these options as the heuristic posits that these earlier generated options will be the higher quality options. The authors suggest that the generation of relatively few options is adequate for making a high quality decision. Johnson and Raab (2003) originally presented this model based on a divergent task completed by intermediate level handball players. After viewing videos from a handball match, which were frozen after 10 seconds, participants were instructed to quickly identify the first option that intuitively came to mind, then as many options as they could conceive, and finally to choose the option they considered to be the best in the specific situation. A negative relationship was reported between the total number of options generated and the quality of participants' final decision and as more options were generated, the quality of those options decreased. Laborde and Raab (2013) extended these findings by demonstrating, using a similar task, that expert performers generated fewer options than near-experts, supporting the suggestion that expert decision making may be underpinned by a "less-is-more" option generation strategy.

Ward et al. (2013) proposed that option generation in complex tasks could be consistent with Long Term Working Memory theory (LTWM, Ericsson & Kintsch, 1995). According to LTWM theory, due to extensive experience and practice within a domain, skilled performers acquire elaborate domain-specific memory representations. Information is proposed to be indexed within these memory representations in such a way that allows performers direct access to both the likely outcome of upcoming events as well as potential relevant alternatives during performance (Ericsson et al., 2000). The adaptability and flexibility of this approach could be particularly important in dynamic, complex tasks (Hoffman et al., 2014).

Ward et al. (2013) required skilled and less-skilled soccer players to anticipate what would happen next after viewing video footage of sequences from matches. Participants generated all the options they thought the opponent might take as well as indicating what they thought the opponent would actually do. To classify the options participants generated relative to the predictions of LTWM theory, a panel of expert coaches classified options as task-relevant or task-irrelevant. In addition to demonstrating that skilled participants were more accurate than less-skilled counterparts, the authors observed that participants generated relatively few options and that skilled participants generated the highest quality option more often as their first option when compared with less-skilled participants. These observations were reported to be consistent with both the TTF heuristic model and LTWM theory. However, rather than skilled participants generating fewer options than less-skilled, as observed by Laborde and Raab (2013) and Klein and Peio (1989), there was no difference between groups in terms of the number of options generated. Yet, there were clear differences in the type of options the two groups of participants generated. Skilled participants generated more task-relevant and fewer task-irrelevant options than less-skilled counterparts. Moreover, performance on the anticipation task was positively and negatively related to the number of task-relevant and task-irrelevant options generated, respectively.

Belling et al. (2015a) extended the work of Ward et al. (2013) by examining the effect of time constraints on option generation strategies when anticipating the intentions of an opponent in possession of the ball and when making a decision about the course of action to take when in possession of the ball oneself. In the time-constrained condition, participants had 10 seconds to complete the task, whereas in the other condition, no time constraint was enforced. The skilled participants generated more task-relevant and fewer task-irrelevant options than less-skilled participants in both the anticipation and the decision making task. In the decision making task, fewer task-irrelevant options were generated in the time-constrained condition than in the non-time-constrained condition; however, this did not hold for the anticipation task. This selective reduction of task-irrelevant options in the decision making task was reported to be consistent with the TTF heuristic model. However, the significant negative correlation between the number of options generated and performance, which would be predicted by the TTF heuristic model, was not observed. Yet, significant positive and negative correlations between task-relevant and task-irrelevant options and performance were observed. The authors tentatively suggested that participants used a strategy that was more consistent with LTWM theory than the TTF heuristic model, both when anticipating the opponent's intentions and when making a decision about what action to take. Their findings suggest that the option generation strategy employed is at least somewhat dependent on the task constraints.

An increasing number of researchers have examined the effect of task constraints on anticipation (e.g., Cocks, Jackson, Bishop, & Williams, 2015; North, Hope, & Williams, 2016; Roca et al., 2013). Murphy et al. (2016) examined how the accuracy of anticipation judgments in skilled and less-skilled tennis players differed depending on the information presented. The authors presented the same rallies from real tennis matches in either animated format, which omitted the bodies and rackets of the players such that participants were constrained to anticipate based solely on contextual information (as would be necessary in a real match when placed under extreme time constraints and the player cannot afford to wait for pertinent postural cues to become available), or video format, in which both contextual information and postural information were available. While participants were able to accurately anticipate the opponent's intentions based on contextual information alone, participants were more accurate when postural cues were also available. Moreover, skilled participants were more accurate regardless of the information available. In a follow-up experiment, the authors collected verbal reports of thoughts while participants viewed the animated footage displaying contextual information only. The verbal reports articulated by the skilled participants were indicative of more elaborate domain-specific memory representations when compared to their less-skilled counterparts, as evidenced by a greater number of evaluation and prediction statements.

It is possible that the cognitive mechanisms underpinning skilled anticipation differ depending on the information available at a given point in time. Müller and Abernethy (2012) proposed a model of anticipation based on the temporal pick-up and use of information in striking sports, in which they suggested that as more information becomes available as the moment of ball contact approaches, the number of action possibilities decreases and that contextual information available prior to the opponent's movement pattern commencing may act to prime the performer for a quick and accurate response when pertinent postural cues become available. In this study, we aim to compare the option generation strategies of skilled and less-skilled tennis players when presented with the information that would normally become available sequentially relative to the opponent striking the ball. We examined how skilled and less-skilled tennis players generate options and anticipate the outcome of an opponent's shot when constrained to do so based on contextual information alone, or when both contextual and postural information are available in the visual display. First, based on the findings of Murphy et al. (2016), we hypothesised that participants would be more accurate when both postural and contextual information were available than when participants were constrained to anticipate based on contextual information alone. Moreover, we expected skilled participants to be more accurate than less-skilled participants and for this difference to be greater when postural information was available than not due to the skilled participants' ability to more effectively pick up and utilise pertinent postural cues from the opponent.

Second, based on previous published reports (Johnson & Raab, 2003; Ward et al., 2013), and consistent with LTWM theory and the TTF heuristic model, we hypothesised that participants would generate relatively few options per trial. Moreover, we hypothesised that participants would generate fewer options when presented with both contextual and postural information than when presented only with contextual information due to the availability of postural cues and resultant reduction of action possibilities (Müller & Abernethy, 2012). Furthermore, we hypothesised that this reduction would be more pronounced in skilled than less-skilled participants due to their greater ability to pick up and utilise pertinent postural cues (Mann et al., 2007).

Third, based on the findings of Ward et al. (2013) and Belling et al. (2015a), and in support of LTWM theory (Ericsson & Kintsch, 1995), we hypothesised that skilled participants would generate more task-relevant and fewer task-irrelevant options than less-skilled participants but we expected this effect to be more pronounced when anticipating based solely on contextual information as the complexity of the task would be greater, potentially making adaptability and flexibility more important (Hoffman et al., 2014).

Finally, we hypothesised that option generation strategies would be consistent with LTWM theory (higher number of task-relevant options and lower number of task-irrelevant options being related to higher levels of performance, Ward et al., 2013).

Methods

Participants

Altogether, 12 skilled (M_{age} = 24.33, *SD* = 4.48) and 14 less-skilled (M_{age} = 24.45, *SD* = 5.41) male tennis players participated. The skilled participants had played tennis for a mean of 18.25 years (*SD* = 6.02), whereas less-skilled participants play recreational tennis irregularly and had never played competitively. The skilled participants held British Tennis ratings of between 1.1 and 4.1, whereas the less-skilled participants did not hold a rating. The rating system is based on competition results with the highest rating possible being 1.1 and the lowest rating being 10.2. One participant in each group was left-hand dominant. All participants had normal or corrected to normal vision. Written informed consent was received from each of the participants and ethical approval was obtained from the lead university's ethics board.

Test Stimuli

Test stimuli were created from points played in professional men's tennis matches at the AEGON Championships (2013). The video condition was created from video footage recorded at 30 Hz using a wide angle lens camera (Contour Roam, Contour Inc., Seattle, USA) from a height of 1.9 m above the ground and 6.4 m behind the court. Player movement and ball trajectory data (Hawk-Eye Innovations Ltd., Basingstoke, UK), taken from the same rallies used in the video condition, were input into a rendering engine to generate footage for the animated condition (see Murphy et al., 2016). The animated footage was generated by omitting the players' bodies and rackets from the visual display such that participants would be constrained to anticipate based on contextual information alone (such as the relative movements of the players, their positioning, and shot sequencing). In these animations, the two players were presented as a blue and a red cylinder, the rackets were not visible, and the ball was presented as a yellow dot. Video footage on the other hand displayed both postural and contextual information as the footage was not manipulated in any way (see Figure 2.1). In both display conditions, trials were edited to occlude at the opponent's racket-ball contact using Pinnacle Studio 15 editing software (Pinnacle, Ottawa, Canada).

Situations in which the player on the near side of the court was placed under extreme time constraints were selected as test stimuli (as per Murphy et al., 2016). Players have been shown to anticipate more often when placed under extreme time constraints, such as when the opponent is attacking from the inside of the court than in neutral situations in which the time constraints are more relaxed (Triolet et al., 2013). These situations were thought to be representative of those in which anticipation would be important in matches. The experimental trials were made of 14 rallies from nine different matches in various rounds of the tournament, featuring 14 different players, all of whom were right-handed. Trials began three seconds prior to the serve being hit and contained between two and seven shots prior to occlusion at the opponent's racket ball contact. The final occluded shots of trials were made up of drives, passing shots, drop-shots, and volleys.

Materials, Apparatus, and Set-Up

Test stimuli were viewed on a 15.6 inch laptop (Hewlitt-Packard, Bracknell, UK). Participants sat approximately 40 cm from the screen yielding a viewing angle of the opposing player of around 2° - 3° (for similar viewing angles, see Cocks et al., 2015; Murphy et al., 2016).

Procedure

Participants viewed eight familiarisation (four video and four animated trials) and 28 experimental trials (14 video and 14 animated trials), with none of the familiarisation trials being used as experimental trials. Six sets of the 28 trials, presented in a random order, were used as test stimuli with two participants from each group viewing one set of trials, except for two of the sets which were viewed by three of the less-skilled participants. Trials were presented in blocks of seven with a one-minute break in between to prevent boredom. In the experimental trials, the first bounce of the ball after the shot on which the trial was occluded was deep (past the service line) on the left and right side (relative to the centre line of the court) on five trials each and short (before the service line) on the left and right side of the court on two trials each.

Participants were told that the length of the rallies would vary and that at some stage in each of the rallies the display would be occluded (i.e., the screen would go black) at the moment of the opponent’s racket-ball contact. They were told that at this point, on a scaled down image of a tennis court on a piece of A4 paper, they should indicate the expected ball bounce location of each of the shots (by drawing an ‘X’ on the court) the opponent might hit when the clip was occluded. They were told that the objective of the task was not to provide an exhaustive list of every possible option they could think of but to indicate only the options they thought of at the moment the clip was occluded. For each option generated, participants were asked to rate the likelihood, on a scale of 0 to 10, with 0 being not at all likely and 10 being certain, that the opponent would hit the shot where the 'X' was placed. The 'X' which received the highest likelihood score was considered their anticipated option (see Belling et al., 2015a). If their anticipated option landed in the same quadrant of the court as the ball actually bounced it was considered correct (see Murphy et al., 2016). A percentage of correct judgments was calculated for depth (correctly anticipating whether the ball bounce location would be short or deep), direction (correctly anticipating whether the ball bounce location would be to the left or right of the centre line) and combined judgments (correctly anticipating the quadrant of the court in which the ball would bounce). Participants were not provided with feedback after any of the trials.

Prior to data collection, two expert coaches with an average of 15 years of experience in tennis, at national and international level, watched all of the video sequences. The coaches identified areas of the court the receiving player should be concerned about the ball being hit to and would therefore be considered task-relevant options for the anticipation task (see Belling et al., 2015a). On an A4 piece of paper, with a scaled schematic of a tennis court on it, the coaches were asked to identify these areas based on the information that they had available to them from the display up until the point of occlusion. The schematic of the tennis court had a grid of 16 (width) by 23 (length) squares on it to allow coaches to easily designate these areas of the court. The procedure differed to that of the participants in that, rather than being asked only to identify shots they thought of at the point of occlusion, they were asked to identify all of the options that should be considered by someone receiving the occluded shot given the available information. Moreover, they were allowed to view the trials as many times as they wished to identify these task-relevant options. The level of agreement between the two coaches was 84.8%. On a separate schematic, the coaches then designated the areas of the court they agreed upon that the receiving player should be concerned about the ball being hit to for each of the trials. This resulted in 34 and 52 relevant areas of the court being identified in the video and animated conditions respectively. The participants' 'X's which were located inside an area of the court identified by the coaches to be an area of concern were deemed task-relevant options, whereas those located outside these areas were deemed task-irrelevant.

Data Analysis

To determine whether there were differences in anticipation response accuracy across display conditions and skill groups, we conducted a 2 (Display [video, animated]) × 2 (Group [skilled, less-skilled]) MANOVA with depth, direction, and combined accuracy scores acting as the dependent variables. To examine whether the number and type of generated options differed between groups and display conditions, we conducted a 2 (Display) × 2 (Group) × 2 (Option Type [task-relevant, task-irrelevant]) ANOVA. In the case of significant interactions, pairwise comparisons were conducted. To examine relationships between numbers and types of options generated and response accuracy, we conducted multiple regressions and follow-up Pearson's correlations. The alpha level was set at .05. Partial eta squared (η_p^2) and Cohen's *d* were used to report effect size. Any violations of sphericity were corrected with Greenhouse-Geisser procedures and in the case of multiple *t*-tests, Sequential Bonferroni was applied.

Results

Response Accuracy

The mean response accuracy and standard error scores for skilled and less-skilled participants are presented in Figure 4.1. MANOVA revealed a significant Display ×

Group interaction, Wilks' Lambda = .54, $F(3,22) = 6.35$, $p < .01$, $\eta_p^2 = .46$. The univariate output revealed that the Display × Group interaction was significant for direction, $F(1,24) = 12.52$, $p < .01$, $\eta_p^2 = .34$, and combined response accuracy scores, $F(1,24) = 18.87$, $p < .01$, $\eta_p^2 = .44$, but not for depth, $F(1,24) = 1.43$, $p = .24$, $\eta_p^2 = .06$. Independent *t*-tests indicated that the interaction was caused by the difference in combined accuracy across groups being greater in the video (skilled: *M* = 68.45%, *SE* = 3.34, less-skilled: *M* = 38.77%, *SE* = 4.01, $p < .01$, *d* = 2.21) compared with the animated condition (skilled: *M* = 50.00%, *SE* = 2.15, less-skilled: *M* = 38.27%, *SE* = 3.14, $p < .01$, *d* = .1.19). Additionally, skilled participants anticipated direction more accurately than less-skilled participants in the video condition (skilled: *M* = 77.38%, *SE* = 3.15, less-skilled: *M* = 64.29%, *SE* = 3.59, $p < .01$, *d* = 1.07), but not in the animated condition (skilled: *M* = 66.67%, *SE* = 2.38, less-skilled: *M* = 71.94%, *SE* = 2.42, $p = .07$ *d* = 0.61).

A significant main effect of Display was observed, Wilks' Lambda = .24, $F(3,22) = 22.84$, $p < .01$, $\eta_p^2 = .76$. The univariate output revealed that the main effect was significant for depth, $F(1,24) = 63.29$, $p < .01$, $\eta_p^2 = .73$, and combined judgments, $F(1,24) = 21.08$, $p < .01$, $\eta_p^2 = .47$, but not direction, $F(1,24) = .35$, $p = .56$, $\eta_p^2 = .01$. Depth and combined response accuracy was higher in the video (depth: *M* = 76.37%, *SE* = 3.11, combined: *M* =52.47%, *SE* = 3.94) than the animated condition (depth: *M* = 61.54%, *SE* = 3.02, combined: *M* = 43.68%, *SE* = 2.25), but there was no difference in response accuracy between the video (*M* = 70.33%, *SE* = 2.71) and animated condition (*M* = 69.51%, *SE* = 1.75) for direction.

A significant main effect of Group was also observed, Wilks' Lambda = .49, $F(3,22) = 7.50$, $p < .01$, $\eta_p^2 = .51$, with the univariate output revealing that the main effect was significant for depth, $F(1,24) = 15.74$, $p < .01$, $\eta_p^2 = .40$, and combined, $F(1,24) = 24.21$, $p < .01$, $\eta_p^2 = .50$, but not direction judgments, $F(1,24) = 1.40$, $p = .25$, $\eta_p^2 = .06$. When anticipating the depth of the opponent's shot, skilled participants were more accurate (M = 78.87%, SE = 3.41) than less-skilled (M = 60.46%, SE = 3.15) participants. The skilled participants' combined accuracy scores were higher (59.23%, SE = 3.09) than those of the less-skilled participants (M = 38.52%, SE = 2.86).

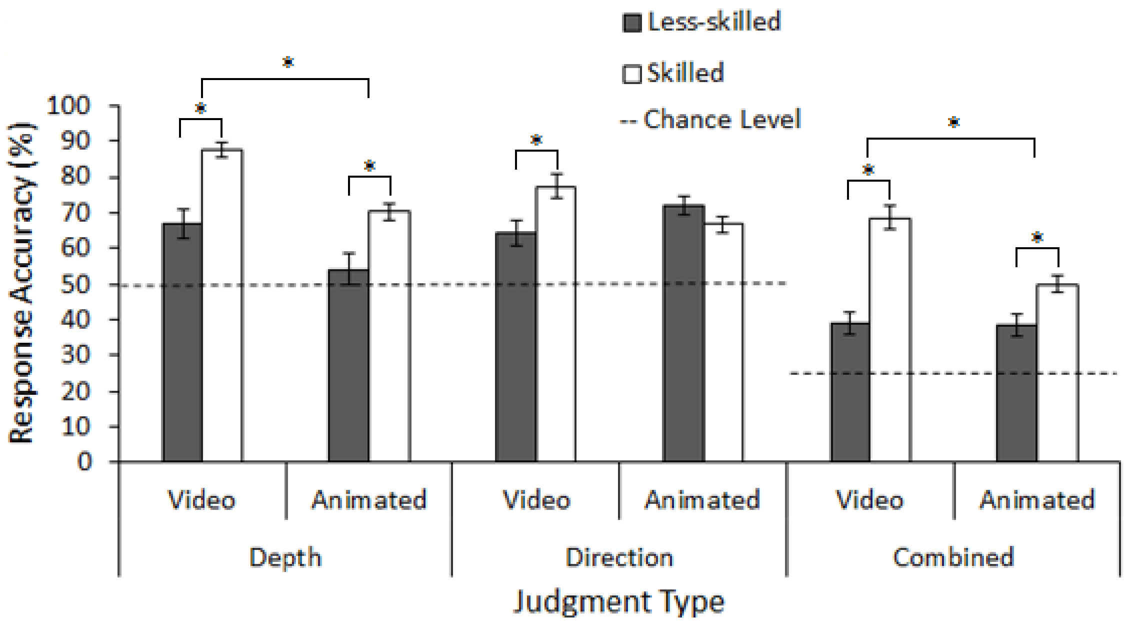


Figure 4.1. Mean (SE) depth, direction and combined response accuracy across groups in video and animated display conditions. *$p < .05$

Option Generation

The mean number of task-relevant and task-irrelevant options for skilled and less-skilled participants is presented in Figure 4.2. Participants generated a mean of 1.85 options per trial (SE = 0.07). ANOVA revealed a significant Display × Group × Option Type interaction, $F(1,24) = 4.67$, $p = .04$, $\eta_p^2 = .16$.

A main effect of Display was observed, $F(1,24) = 23.07$, $p < .01$, $\eta_p^2 = .49$. Participants generated fewer options in the video condition ($M = 1.74$, $SE = .08$) than in the animated condition ($M = 1.96$, $SE = .07$). The reduction from animated to video was greater in skilled (animated: $M = 1.95$, $SE = .11$, video: $M = 1.64$, $SE = .09$, $p < .01$, $d = 0.93$) than less-skilled (animated: $M = 1.97$, $SE = .10$, video: $M = 1.84$, $SE = .12$, $p = .04$, $d = .33$) participants. The Display × Group interaction was not significant, $F(1,24) = 3.40$, $p = .08$, $\eta_p^2 = .12$.

A significant Display × Option Type interaction, $F(1,24) = 14.92$, $p < .01$, $\eta_p^2 = .38$, was observed. Participants generated more task-relevant options in the animated condition than in the video condition (animated: $M = 1.07$, $SE = .08$, video: $M = .80$, $SE = .05$, $p < .01$, $d = 0.83$), but no difference in the number of task-irrelevant options generated was observed between the two conditions (animated: $M = .90$, $SE = .08$, video: $M = .95$, $SE = .08$, $p = .17$, $d = 0.15$).

A significant Group × Option Type interaction, $F(1,24) = 36.06$, $p < .01$, $\eta_p^2 = .60$, was observed. Follow-up *t*-tests revealed that skilled participants generated more task-relevant (skilled: $M = 1.14$, $SE = .06$, less-skilled: $M = 0.76$, $SE = .06$, $p < .01$, $d = 1.74$) and fewer task-irrelevant (skilled: $M = .65$, $SE = .07$, less-skilled: $M = 1.15$, $SE = .09$, $p < .01$, $d = 1.72$) options than less-skilled participants.

To further investigate the source of the Display × Group × Option Type interaction, a further ANOVA was run in each display condition. The Group × Option Type interaction was significant in both the video, $F(1,24) = 18.83$, $p < .01$, $\eta_p^2 = .44$, and the animated condition, $F(1,24) = 35.09$, $p < .01$, $\eta_p^2 = .59$. Independent *t*-tests revealed that while skilled participants generated more task-relevant and fewer task-irrelevant options in both conditions the differences between groups were smaller in the video condition (relevant: M_{diff} = 0.25, *SE* = 0.08, $p < .01$, d = 1.27, irrelevant: M_{diff} = 0.44, *SE* = 0.14, $p < .01$, d = 1.32) than in the animated condition (relevant: M_{diff} = 0.52, *SE* = 0.12, $p < .01$, d = 1.79, irrelevant: M_{diff} = 0.55, *SE* = 0.12, $p < .01$, d = 1.84). Pairwise comparisons revealed that neither skilled (animated: *M* = 0.60, *SE* = 0.09, video: *M* = 0.71, *SE* = 0.07, p = .06, d = 0.41) nor less-skilled participants (animated: *M* = 1.15, *SE* = 0.08, video: *M* = 1.15, *SE* = 0.11, p = .48, d = 0.01) differed in the number of task-irrelevant options generated between the animated and the video condition. However, skilled participants reduced the number of task-relevant options generated between the animated (*M* = 1.35, *SE* = 0.07) and video conditions (*M* = .93, *SE* = 0.05, $p < .01$, d = 1.85) more than less-skilled participants (animated: *M* = .83, *SE* = 0.09, video: *M* = .68, *SE* = 0.05, p = .04, d = 0.53).

Finally, neither a main effect of Option Type, $F(1,24) = .40$, $p = .54$, $\eta_p^2 = .02$, nor a main effect of Group, $F(1,24) = .57$, $p = .46$, $\eta_p^2 = .02$, was observed.

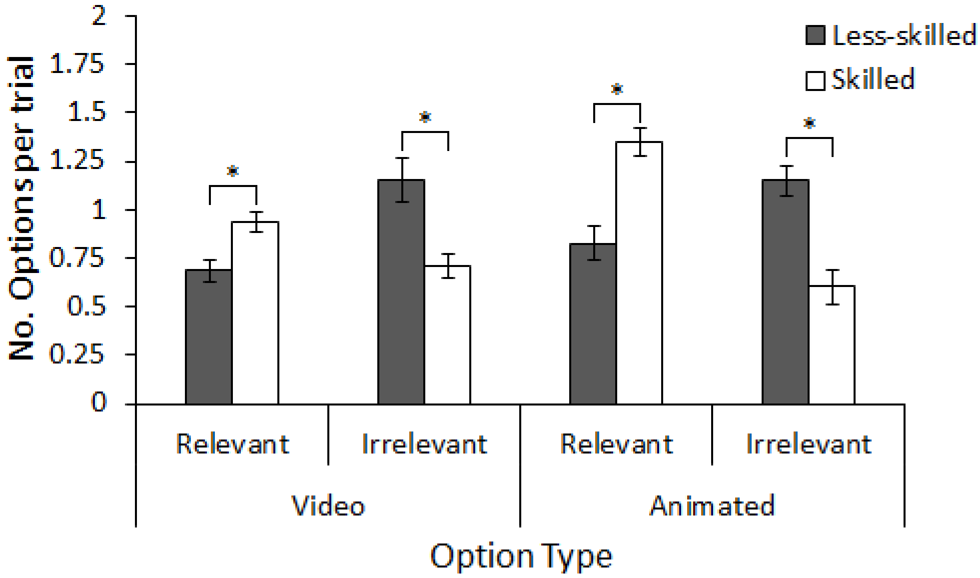


Figure 4.2. Mean (SE) number of task-relevant and task-irrelevant options generated per trial by skilled and less-skilled participants in video and animated display conditions. *$p < .05$

Relationship between Option Generation and Response Accuracy

The relationships between option generation and response accuracy are presented in Figures 4.3 and 4.4. A significant negative relationship was observed between the number of options generated and combined response accuracy in the video condition (r = -.44, p = .01). This relationship was not significant in the animated condition (r = -.25, p = .11). Further Pearson's correlations within skill groups revealed no significant relationships between number of options generated and combined accuracy for either group in the video condition (skilled: r = -.23, p = .24, less-skilled: r = -.46 p = .05) or the animated condition (skilled: r = -.17, p = .30, less-skilled: r = -.34 p = .12), with these negative relationships being stronger for the less-skilled than the skilled participants.

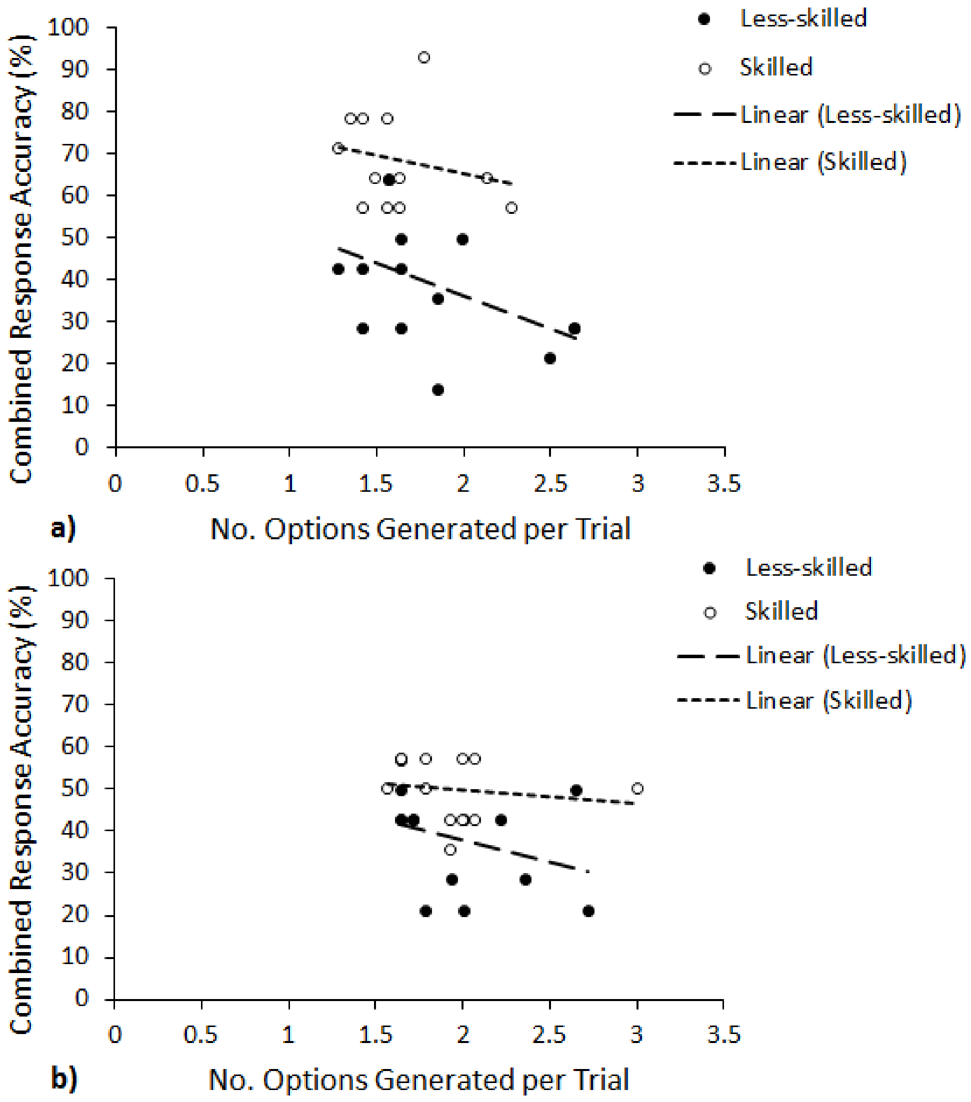


Figure 4.3. The relationship between mean number of options generated and combined response accuracy across groups in video (a) and animated (b) display conditions.

Multiple regression revealed that the number of task-relevant and task-irrelevant options significantly predicted combined accuracy in the video condition (R^2 = .41, F(2,25) = 7.94, p < .01). Pearson's correlations revealed a moderate, significant positive relationship between the number of task-relevant options generated and combined accuracy (r = .35, p = .04) and a strong, significant negative relationship between the number of task-irrelevant options generated and combined accuracy (r = -.62, p < .01). The number of task-relevant and task-irrelevant options significantly predicted combined accuracy in the animated condition (R^2 = .36, $F(2,25)$ = 6.33, p < .01). Pearson's correlations revealed a moderate, significant positive relationship between the number of task-relevant options generated and combined accuracy (r = .38, p = .03), and a strong, significant negative relationship between the number of task-irrelevant options generated and combined accuracy (r = -.60, p < .01).

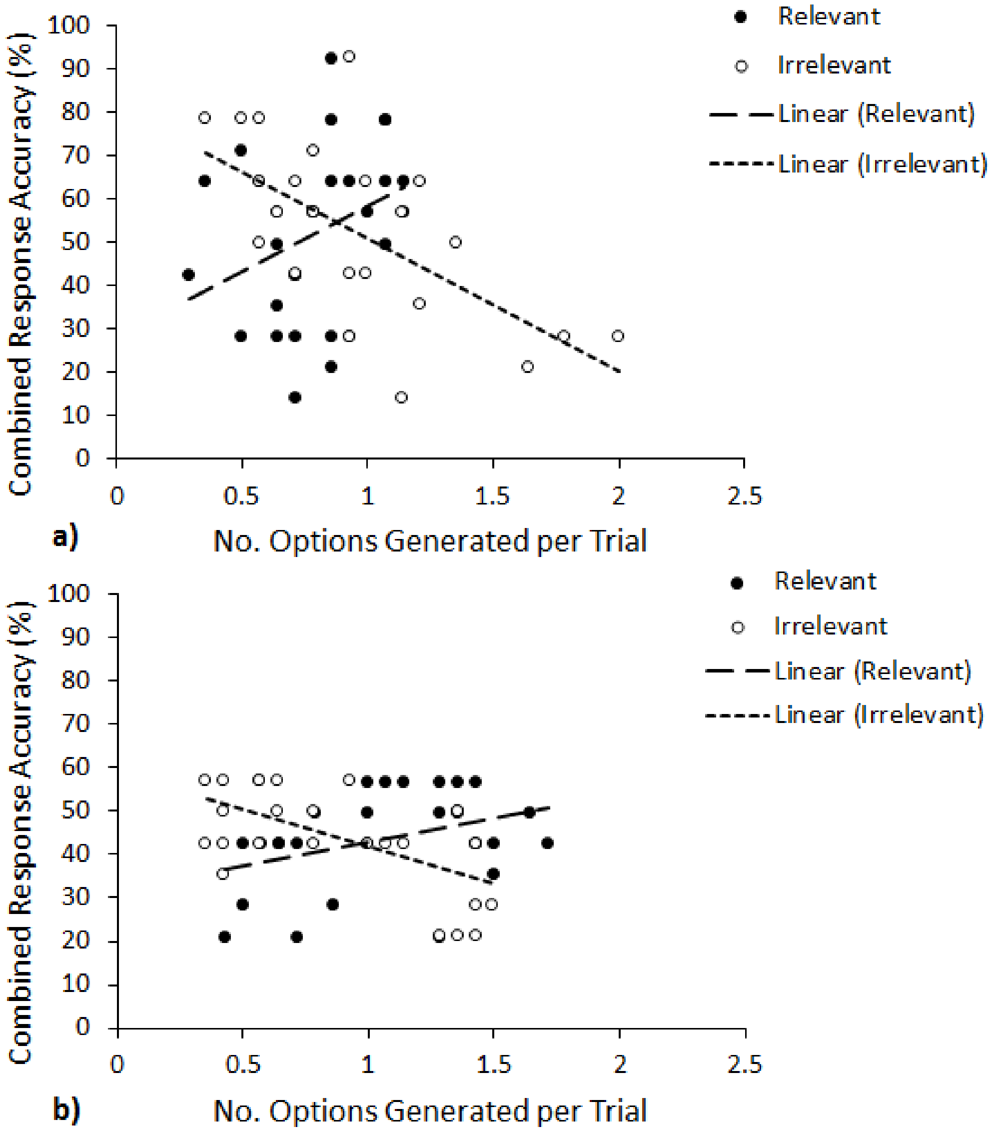


Figure 4.4. The relationship between mean number of task-relevant and task-irrelevant options generated and combined response accuracy in video (a) and animated (b) display conditions.

Discussion

We compared the option generation strategies employed by skilled and less-skilled tennis players when completing a task in which they were required to anticipate the outcome of an opponent's shot based on contextual information alone (animations) or when both postural and contextual information (videos) was available. We expected, based on previous published reports, to observe differences in response accuracy (Abernethy et al., 2001; Loffing & Hagemann, 2014; Murphy et al., 2016) and option generation strategies (Belling et al., 2015a, 2015b; Johnson & Raab, 2003; Ward et al., 2013) between skill groups and display conditions.

As expected response accuracy was higher when pertinent postural cues were available for processing in the video condition than when constrained to respond based on contextual information alone in the animated condition (Murphy et al., 2016). The increase was evident for depth and combined judgments, but not direction judgments. In line with our other hypotheses, skilled participants were more accurate than less-skilled participants overall, with this difference in accuracy being more pronounced in the video condition. In particular, the differences across groups were greater for direction and combined judgments in the video than the animated condition. This finding was expected because skilled performers are more effective in picking up pertinent postural cues from an opponent's movement pattern. Overall, these findings reinforce previous published reports (e.g., Abernethy et al., 2001; Murphy et al., 2016) and suggest that contextual information can be used to anticipate highly effectively, yet if performers are afforded the time to wait for pertinent postural cues to become available, doing so can result in more accurate anticipation.

As expected, participants generated fewer options when viewing rallies in the video condition than when viewing the same rallies in the animated condition. Participants adapt their option generation strategy depending on the information they have available to them at a given moment in time. Moreover, we suggest that this finding could represent how tennis players generate and subsequently reduce the number of options they consider on approach to the opponent striking the ball. When players are constrained to anticipate based on contextual information in advance of pertinent postural cues becoming available (Buckolz et al., 1988; Farrow & Abernethy, 2015; Müller & Abernethy, 2012), they appear to generate all likely options (rather than all possible options, which would likely result in a much higher number of options being generated). As the movement pattern that the opponent will use to strike the ball develops, pertinent postural cues are picked up which result in some previously considered options being deemed highly unlikely and being disregarded. Consequently, players have fewer options to choose from when making a final decision nearer the moment of racket-ball contact. This proposed strategy is consistent with Müller and Abernethy's (2012) model which suggests that the number of action possibilities associated with the opponent's intentions reduces as racket-ball contact on the final stroke of the rally approaches.

Participants reduced the number of task-relevant options generated, but not task-irrelevant options, from the animated to the video condition. These findings differ from those of Belling et al. (2015a) who observed that participants reduced the number of task-irrelevant options generated when making decisions under time constraint, however, recall that no such differences were observed in the anticipation task they conducted under time constraint. Our findings suggest that the number and type of options performers generate differ depending on the informational constraints. While the findings of Belling et al. may have been expected because reducing the number of task-irrelevant options generated when under time constraint would result in a higher proportion of relevant options from which to base a quick and accurate decision, our findings indicate that the number of task-relevant options performers generate depends on the information available at that moment. The higher response accuracy scores in the video condition when compared with the animated condition indicate that reducing the number of task-relevant options generated when postural cues were available was an effective strategy.

We predicted that the reduction in the number of options generated from the animated to the video condition would be more pronounced for skilled than less-skilled participants. In particular, less-skilled participants were not expected to be able to use the postural cues to reduce the opponents' action possibilities in the same way as a skilled performer. However, the Group × Display interaction did not reach significance. One possible explanation is that the third person viewing angle used in our task made participants more reliant on contextual information (picked up from the relative movements/positioning of the players and shot sequencing) than they normally would be in competition, reducing reliance on pertinent postural cues in the video condition (Roca et al., 2013). In future, researchers should attempt to recreate the viewing perspective experienced in a real-world situation.

In keeping with the findings of Ward et al. (2013) and Belling et al. (2015a), and in line with our hypothesis, skilled participants generated significantly more task-relevant and fewer task-irrelevant options than less-skilled participants. This finding provides support for the notion that skilled performers develop LTWM skills which allow them to encode and maintain access to task-relevant information. We further hypothesised that this effect would be stronger in the animated condition than in the video condition because skilled performers have developed LTWM skills that allow them to be more adaptable in more complex and less predictable situations, such as when constrained to anticipate based on contextual information in advance of pertinent postural cues becoming available (Hoffman et al., 2014). As predicted, the associated effect size for this interaction was larger in the animated than in the video condition. We suggest that when constrained to anticipate based on contextual information, as performers sometimes have to do in a competitive situation prior to pertinent postural cues becoming available (Triolet et al., 2013), skilled performers employ an option generation strategy consistent with LTWM theory which allows access to both the perceived most likely outcome and potential relevant alternatives.

The relationships between the number and type of options generated and performance suggest that the cognitive mechanisms underlying anticipation may differ depending on the information available when generating options. In the video condition, consistent with the TTF heuristic model, a negative relationship was observed between the number of options generated and performance, whereas this relationship was not significant in the animated condition. While such a "less-is-more" strategy may be effective when presented with pertinent postural cues, it could be less effective when constrained to anticipate prior to such cues becoming available. Numerous researchers have identified specific cues which can be picked up from an opponent to anticipate (e.g., Causer et al., 2017; Huys et al., 2009; Jackson & Mogan, 2007). If one is able to pick up these cues, generating the low number of options associated with these cues and not further generating options based on contextual information is likely to yield a high level of success. However, we note that the negative relationship observed between the number of options generated and performance was weaker in skilled compared to less-skilled participants, suggesting that these data should be interpreted carefully if the findings are to be used to design training programmes to develop anticipation skill in skilled performers. On the other hand, regardless of the information presented, performance levels were positively and negatively associated with the number of task-relevant and task-irrelevant options generated respectively. We suggest that while a less-is more strategy may be effective when pertinent postural cues are available for processing, it appears beneficial for the performer to generate and maintain access to potential relevant alternatives. This strategy may be particularly important in situations in which the outcome is not entirely congruent with the postural information presented in the lead up to the critical event, for example, due to varying levels of disguise or deception (Jackson et al., 2006; Sebanz & Shiffrar, 2009).

Our research findings provide support for the notion that perceptual-cognitive training in complex, dynamic tasks should be context-specific (Hoffman et al., 2014). While Belling et al. (2015a) suggested that the option generation strategies employed when making decisions are affected by time constraints, our findings indicate that the option generation strategy employed when anticipating is dependent on the information available. We recommend that training programmes be designed to reflect these differences. For example, performers should be trained to develop the skills needed to pick up and utilise both contextual and postural information to inform their judgments, given that depending on the time constraints, they will often have to base their judgments on one or both of these types of information. We suggest that training should be focused on developing the LTWM skills which allow performers to rapidly encode and subsequently access task-relevant options specific to the situation. The development of such skills means that when performing under particularly extreme time constraints performers can prioritise the generation of task-relevant options based on available contextual information. However, training for situations in which pertinent postural cues as well as contextual information are available appears less straight forward. On the one hand, it appears that the generation of all available task-relevant options is a sensible strategy, yet on the other, it appears that a more intuitive strategy may be more suitable.

In the current study, participants were instructed to only highlight options that they considered at the moment of the clip being occluded. A potential limitation of the task employed, however, is the possibility that participants highlighted options that they generated some period of time afterwards. The absence of a time constraint may have made this possibility more likely, as well as resulting in the employment of option generation strategies that may not necessarily be effective or utilised while performing in competition. While Belling et al. (2015a) have investigated the option generation strategies of skilled athletes under time constraints, the time constraints were not as strict as would be experienced in competition (a time constraint of ten seconds was enforced). We therefore suggest that, in future, researchers attempt to more closely recreate the temporal demands experienced in the competitive environment.

In future, researchers should also attempt to determine the extent to which contextual information should be relied upon when anticipating an opponent's intentions. For example, in situations in which the performer can afford to wait for pertinent postural cues to become available, they should potentially be trained to generate options based solely on this information due to it potentially being more reliable. However, there are likely to be situations in which the postural cues the opponent is displaying are difficult to pick up and contextual information may enhance performance. While research is emerging which demonstrates that contextual information can have both a positive and a negative effect on anticipation (e.g., Gray, 2002a; Loffing et al., 2015; Mann et al., 2014), additional work is needed to present stronger recommendations relating to the specific information that developing performers should attend to in different situations (e.g., under different levels of time constraint).

In sum, we have demonstrated that the option generation strategies associated with effective anticipation appear dependent on the information performers are constrained to use at any particular moment in time. As more information becomes available as the critical event approaches (i.e., racket-ball contact by the opponent), skilled performers tend to generate less options, implying that both contextual and postural information are effectively processed and prioritised. Moreover, when constrained to anticipate based on contextual information alone, which would often be necessary under extreme time constraints, option generation strategies which facilitate access to potential relevant alternatives, in addition to the likely outcome, and are therefore consistent with LTWM theory, appear optimal. Conversely, when performers can afford to wait for pertinent postural cues to become available, generation of less options, and potentially a switch towards a strategy consistent with more intuitive models such as the TTF heuristic may be optimal. Our findings highlight the dynamic and interactive nature of perceptual-cognitive expertise.

Chapter 5

Epilogue

In this chapter, the aims of the thesis are reiterated and the main findings of the thesis, as well as theoretical and practical implications, outlined. Potential limitations of the research will be highlighted and future research directions proposed. Finally, the complex nature of anticipation will be discussed with particular reference to the outstanding issues that need to be addressed to inform the development of an overarching theoretical framework of expert anticipation.

Aims of the thesis

Since the emergence of anticipation as a determining factor in expert sports performance (Jones & Miles, 1978), the majority of research attention in this area has been focused on identifying relevant cues emanating from an opponent's body movements and postural orientation (Crognier & Féry, 2007; Mann et al., 2007). However, published research suggests that, particularly in extremely temporally-constrained conditions, expert performers often rely on contextual information to anticipate, prior to pertinent postural cues becoming available from the opponent (Triolet et al., 2013). While an increasing number of researchers are investigating how contextual information influences expert anticipation, historically researchers may have understated its importance in anticipation (Cañal-Bruland & Mann, 2015). Therefore, the overall aim of this thesis was to examine the role of contextual information in expert anticipation. A variety of methods were employed to do so over the course of five studies. The extent to which contextual information facilitates anticipation relative to when pertinent postural cues are available was investigated, the specific sources of contextual information facilitating anticipation explored, and the processes and mechanisms underpinning expert anticipation examined.

Thus far, researchers have only been able to infer that expert performers can use contextual information to anticipate effectively in advance of pertinent postural cues becoming available (e.g., Abernethy et al., 2001; Triolet et al., 2013). In Chapter 2 (Studies 1 and 2), a novel approach was taken to determine, under controlled conditions, the extent to which contextual information can be used to anticipate the opponent's intentions and how postural cues presented in addition to contextual information further affects the accuracy of such judgments. In Study 1, skilled and less-skilled tennis players anticipated the intentions of an opponent when viewing open-play rallies from real tennis matches in two display conditions; a video condition that depicted all information that would normally be available when playing a rally (i.e., both contextual and postural information), and an animated condition that constrained participants to anticipate based on contextual information alone. In Study 2, the perceptual-cognitive processes underlying expert anticipation when constrained to anticipate based on contextual information were examined through the collection of gaze data and verbal reports of thoughts.

In recent years, a handful of researchers have investigated whether specific individual sources of contextual information influence skilled anticipation (see Cañal-Bruland & Mann, 2015 for a review). However, these research studies have generally focused on examining isolated sources of contextual information. During anticipation, performers may rely on multiple different sources of information to anticipate the opponent's intentions (Schläppi-Lienhard & Hossner, 2015). Moreover, to ascertain the sources of contextual information which may be relied upon when placed under extreme time constraints, experimental research that controls the presentation of pertinent postural cues is required, such that the sources of contextual information used to anticipate when these cues are not ordinarily available can be ascertained. In Chapter 3 (Studies 3 and 4), the animated display condition was manipulated, such that potential sources of contextual information were depicted or omitted. In Study 3, to determine the extent to which the preceding shot sequence provides contextual information that can facilitate anticipation, the animated footage was manipulated to present participants with sequences of varying length preceding the final occluded shot. In Study 4, the animations were manipulated such that participants were presented with the ball, the players, or both, in dynamic or still format to determine the extent to which the relative movements and final positions of the players and the ball facilitate anticipation. Additionally, in Study 4, confidence ratings associated with participants' responses were recorded to ascertain awareness of the information being used to anticipate the intentions of the opponent.

The process of generating options prior to choosing the most likely event outcome has received surprisingly little research attention (for exceptions, see Belling et al., 2015a, 2015b; Ward et al., 2013). Müller and Abernethy (2012) suggested that far in advance of event occurrence, expert performers rely on contextual information to anticipate the opponent's intentions, with the potential action possibilities being many at this stage. As pertinent postural cues become available however, the number of action possibilities decrease with expert performers being able to adjust their behaviour accordingly to more accurately anticipate the opponent's intentions. In Chapter 4 (Study 5), the option generation strategies underpinning anticipation based on the information which would normally become available sequentially (contextual then postural information) in a real-world setting were investigated. As in Study 1, skilled and less-skilled tennis players viewed videos and animations of rallies from real tennis matches. Upon occlusion at the opponent's racket-ball contact, participants generated all shots they thought the opponent might hit and indicated the option they considered most likely. The extent to which the option generation strategy employed was affected by the informational constraints was determined. Moreover, to determine the cognitive mechanisms underpinning option generation and anticipation, results were examined relative to the predictions of Long Term Working Memory theory (Ericsson & Kintsch, 1995) and the Take The First heuristic model (Johnson & Raab, 2003).

Summary of key findings

In Study 1, response accuracy of both skilled and less-skilled participants was significantly higher than chance when anticipating based on contextual information alone, indicating the importance of contextual information in anticipation. Moreover, response accuracy further increased when postural information was also available for processing. This finding supports previous work that has demonstrated the importance of postural information as a source of relevant cues for anticipation (Mann et al., 2007). Skilled participants were more accurate than less-skilled participants in both display conditions, with the between-groups difference being more pronounced in the video than the animated condition. This effect was particularly evident when anticipating the direction of the opponent's shot. These are the first research findings to demonstrate, in controlled conditions, that contextual information can be used to anticipate accurately, independent of postural cues. Moreover, although contextual information can be used to anticipate effectively, skilled participants in particular appear to be able to integrate pertinent postural cues with contextual information to anticipate more effectively when both types of information are available. The observed differences suggest that the ability to anticipate based on contextual information, and to integrate postural cues with contextual information when available, is a result of adaptations due to experience and practice within the domain.

In Study 2, when constrained to anticipate based on contextual information alone, skilled participants employed different gaze strategies, fixating on the ball for longer than less-skilled participants. Moreover, skilled participants reported more evaluation statements than less-skilled participants, with the number of predictions statements, descriptively, being greater. Consistent with LTWM theory (Ericsson & Kintsch, 1995), this finding suggests that expert performers develop more elaborate domain-specific memory representations which allow them to engage in greater consideration and assessment of the presented contextual information than less-skilled counterparts. Rather than merely monitoring the information presented in the visual display, skilled participants appeared able to draw upon prior experience and knowledge of potential event outcomes to anticipate more effectively than less-skilled counterparts based on the sequential relative movements and positioning of the players and the ball in the absence of pertinent postural cues.

In Study 3, participants were able to anticipate the direction of an opponent's shot more accurately when the preceding shot sequence was presented than when it was not, with this effect being stronger for skilled than less-skilled participants. Moreover, the important information appeared to be picked up from the sequence of shots played immediately prior to the final occluded shot, rather than players being able to utilise earlier shots in the sequence to facilitate anticipation. These findings suggest that the preceding shot sequence is an important source of contextual information which skilled tennis players have learnt to use to anticipate the direction of an opponent's shot more effectively.

In Study 4, participants were shown to require very little information from the visual display to accurately anticipate the opponent's intentions (e.g., solely the final positioning of the players or solely the motion of the ball). The relative movements and final positioning of the players were shown to be a particularly useful source of contextual information, in comparison to the motion and final positioning of the ball. However, participants anticipated most accurately when both the ball flight and player movement was available. There was a strong positive correlation between response accuracy and confidence only when both players and the ball were dynamically presented, suggesting that skilled participants were only aware of the information they were using to anticipate accurately in this condition (Chan, 1992). These findings further suggest that the ability to anticipate based on contextual information alone appears to be due to the development of elaborate knowledge bases which are consciously accessible during anticipation.

In Study 5, participants generated less options when pertinent postural cues were available than when constrained to anticipate based on contextual information alone. Consistent with Müller and Abernethy's (2012) model of anticipation, the skilled participants in particular, tended to reduce the number of options they generated as the number of action possibilities decreased with the availability of pertinent postural cues. Moreover, in line with LTWM theory (Ericsson & Kintsch, 1995), skilled participants generated more task-relevant and fewer task-irrelevant options than less-skilled participants. The number of task-relevant and task-irrelevant options participants generated were also positively and negatively correlated with response accuracy, respectively. Skilled performers appear to develop LTWM skills which facilitate encoding and subsequent access to task-relevant information during performance. In contrast to the TTF heuristic model (Johnson & Raab, 2003), no significant relationships were observed between the number of options generated and response accuracy when constrained to anticipate based on contextual information alone. However, a medium size negative relationship was observed in the video condition, suggesting that expert anticipation when more reliable postural cues are available may be characterised by more intuitive decision making (e.g., as suggested by the TTF heuristic model).

Theoretical implications

Over the course of five studies, it was demonstrated that contextual information can be used to anticipate highly accurately, independent of pertinent postural cues. Moreover, relatively little contextual information was needed to achieve high levels of accuracy. For example, participants were able to anticipate the quadrant of the court the ball was ultimately hit to on approximately 52% of trials when only the final positioning of the players was presented (compared to chance levels of 25%). Although participants became more accurate when pertinent postural cues were available for processing (Studies 1 and 5), the high accuracy scores relative to chance levels when these cues were not available highlights the important role of contextual information in anticipation. Moreover, it suggests that, historically, researchers may have understated the role of contextual information in anticipation. Particularly when placed under extreme time constraints, skilled performers are thought to anticipate based on contextual information in advance of pertinent postural cues becoming available (Triolet et al., 2013). Given that response accuracy remains high even when relatively little contextual information is available from the visual display, using this information to anticipate the opponent's intentions when placed under extreme time constraints appears to be an extremely effective strategy.

Both skilled and less-skilled participants achieved high levels of accuracy when constrained to anticipate based on contextual information alone. This finding is in contrast with those of Abernethy et al. (2001), who originally demonstrated that the anticipatory movements of skilled, but not less-skilled performers, were more accurate than chance far in advance of the opponent striking the ball. The authors concluded that these accurate anticipatory movements were due to the ability of skilled participants to use contextual information more effectively than less-skilled counterparts, who needed later occurring postural cues to anticipate more accurately than chance. Conversely, the findings of this thesis suggest that although there appears to exist some specific sources of contextual information that skilled tennis players have learnt to pick up and use more effectively than less-skilled players (e.g., shot sequencing), there also exist sources of non- domain-specific contextual information which can be picked up by performers of any level to anticipate accurately, provided they know the goal of the activity. Nevertheless, across the five studies, skilled participants were more able to glean useful contextual information from the visual display to anticipate the intentions of an opponent than less-skilled counterparts.

The higher levels of accuracy achieved by skilled in comparison to less-skilled participants across the five studies suggest that the ability to pick up and utilise contextual information to anticipate the intentions of an opponent is due to perceptual-cognitive adaptations resulting from experience and practice in the domain. On the whole, the findings of the thesis are consistent with the mechanisms proposed by LTWM theory (Ericsson & Kintsch, 1995). For example, in Study 2, the thought processes of skilled participants, when constrained to anticipate based on contextual information alone, indicated greater evaluation of the presented information against more elaborate domain-specific memory representations than less-skilled participants. Moreover, in Study 5, the generation of more task-relevant and fewer task-irrelevant options suggested that the retrieval structures involved in expert anticipation do not prescribe a set response, but rather provide access to relevant alternative options. Researchers have previously demonstrated that the cognitive mechanisms proposed by LTWM theory support expert anticipation when pertinent postural cues are available for processing (e.g., McRobert et al., 2009; Roca et al., 2011; Ward et al., 2013). Similarly, support for LTWM theory has been provided in pattern recognition tasks that have omitted postural information from the display (e.g., North et al., 2011). However, this is the first body of research to provide support for the cognitive mechanisms proposed by LTWM theory in a task which constrains participants to anticipate based on contextual information alone.

Based on adjustments made to gaze strategy by skilled batters when viewing the same opponent over consecutive bowls, McRobert et al. (2011) suggested that the batters integrated contextual information about the bowler’s action tendencies into the underlying memory representation. To account for the extreme spatiotemporal constraints expert batters experience in real-world situations, they appear to develop LTWM skills that allow them to integrate contextual information picked up from a bowler’s action tendencies into the existing representation over a series of consecutive actions. The findings of this thesis suggest that to account for the extreme time constraints which often force expert tennis players to anticipate in advance of pertinent postural cues becoming available, they develop LTWM skills that allow them to use contextual information picked up from the preceding shot sequence or final positioning of the players and the ball to anticipate effectively. Similar to the findings of McRobert et al. (2011), skilled tennis players may integrate the preceding shot sequence (Study 3) into the existing representation to anticipate more effectively than when this information is not available, whereas less-skilled participants do not possess the necessary skills to do so or the relevant associated domain-specific knowledge to interpret the additional contextual information.

Whereas McRobert and colleagues investigated how contextual information was used to anticipate more accurately than when it was not available, this thesis was used to investigate how contextual information was used to anticipate when pertinent postural cues were not available for processing. According to LTWM theory (Ericsson & Kintsch, 1995), through experience and practice in similar time-constrained conditions, information about the shot sequences, player positions and resulting outcomes is likely to be encoded in LTM where it is linked to a retrieval structure specific to the demands of that situation. When similar information is subsequently encountered, the retrieval structure can be activated to retrieve associated domain-specific knowledge, and access relevant potential alternative outcomes. This would suggest that when expert tennis players encounter sequential relative movements of the players and the ball in the lead up to the opponent's shot, they can access relevant potential alternatives to accurately anticipate the event outcome, even when they do not have access to pertinent postural cues (Study 5).

It appears that the conscious process of accessing relevant information from LTM is only achieved when the presented information is in a form that closely represents how it has been encountered multiple times previously. In Study 4, neither skilled nor less-skilled tennis players were aware of the information they used to accurately anticipate the opponent's intentions when the visual display presented information in still rather than dynamic form, or when either the players or the ball were omitted. It was only when both the players and the ball were presented dynamically, in the form that skilled players would have previously encountered and engaged with (barring the absence of postural information), that they were consciously aware of the information they were using to anticipate accurately. These findings highlight the importance of consciously engaging with contextual information and associated potential event outcomes during practice and competition such that this information can be encoded into the memory representation and retrieved when subsequently encountered to facilitate anticipation.

Practical implications

From a practical perspective, being able to effectively pick up and utilise contextual information prior to pertinent postural cues becoming available is likely to serve two purposes. First, it allows skilled performers to accurately anticipate the intentions of the opponent when extreme time constraints mean that they cannot afford to wait for pertinent postural cues to become available (Triolet et al., 2013). Second, in situations of slightly less extreme time constraints, it may prime a rapid response for when more confirmatory information from pertinent postural cues become available (Müller & Abernethy, 2012). The differences in response accuracy between skilled and less-skilled participants in Studies 1 and 5 in particular suggest that coaches should ensure that the practice conditions provide the learner with the opportunity to develop the skills needed to anticipate based on contextual and postural information, independently and in conjunction with one another. Potentially, a constraints-led approach could be taken to allow the coach to implement planned activities which mimic the spatiotemporal constraints that encourage anticipation behaviour based on each type of information to emerge (Davids, Button, & Bennett, 2008). However coaches approach this issue, there is clearly a need to ensure that, while training, athletes are exposed to the various sources of information that will be available to them during competition.

In addition to on-court training, advances in technology have made the development of cognitive training tools employing video-based simulations increasing possible (Cummins & Craig, 2016). While research investigating the effectiveness of such training tools for highly skilled performers is limited, the few available studies show promising results (e.g., Belling & Ward, 2015; Hopwood, Mann, Farrow, & Nielson, 2015). However, these studies, as well as those conducted with less-skilled performers (e.g., Abernethy et al., 2012; Williams et al., 2002) have generally focused on developing one aspect of anticipation, e.g., anticipating a particular stroke based on postural cues. The emerging body of research on perceptual-cognitive expertise suggests that athletes need to develop an ability to pick up and utilise both postural cues and contextual information such as shot sequencing (Study 3), player positioning (Study 4), score (Runswick et al., 2017) and opponent action tendencies (Mann et al., 2014) to perform at a high level. As more sources of information contributing to anticipation emerge, the challenge for those designing cognitive training tools is to find innovative ways to develop the athlete's ability to effectively utilise each of these information sources.

In Study 5, it was demonstrated that when constrained to anticipate based on contextual information alone, skilled participants generated and considered more than one task-relevant option. Having access to relevant alternative options and considering fewer task-irrelevant options appears to allow skilled performers to anticipate highly accurately if constrained to do so in advance of pertinent postural cues becoming available. When time constraints are slightly less extreme, because contextual information can already be picked up from the sequential relative movements of the players and the ball to generate highly accurate expectations of the upcoming event, the player may use later arising postural cues merely to confirm or reject initial expectations (Gottsdanker & Kent, 1978). This can be inferred, to some extent, from the lower number of relevant options generated by skilled participants in the video compared to the animated condition in Study 5. While some potential outcomes may be likely based on the preceding shot sequence or the positioning of the players, the likelihood of the opponent hitting certain shots is reduced as pertinent postural cues emerge from the opponent's movement pattern. Skilled participants in particular appear to use these postural cues to disregard certain potential event outcomes as being highly unlikely, thereby anticipating more accurately. It therefore appears that training interventions aimed at developing the skills needed to anticipate effectively in advance of pertinent postural cues becoming available should focus on identifying task-relevant options and ignoring task-irrelevant options. Moreover, as the movement pattern of the opponent develops, the focus should be on identifying pertinent postural cues such that previously generated options can be confirmed as highly likely or disregarded as being highly improbable where applicable.

A further practical consideration is the extent to which the skills developed during training transfer to the real-world environment and how practitioners should assess this. Although researchers have attempted to create realistic transfer conditions by employing on-court transfer tests in which the athlete returns shots from a live opponent (e.g., Broadbent et al., 2015; Williams et al., 2002) the emerging research suggests that these tests do not fully recreate the context-laden conditions of the real-world competitive environment. Potentially, the most feasible and affordable solution for practitioners to assess anticipation in real-world situations is to marry performance analysis methods with verbal reports. An initial analysis of the athlete's observable anticipation behaviour (Triolet et al., 2013) could provide a broad indication of where anticipation skill deficiencies lie, while the collection of verbal reports (e.g., Study 2; McPherson, 1999) when viewing selected rallies could provide confirmation of a lack of awareness of the relevance of particular information sources.

The findings of this thesis are of particular relevance to fast ball sports such as tennis but are also of relevance to other sports and other domains in which the spatiotemporal constraints involved often require the performer to make quick and accurate judgments based on limited information (e.g., aviation, driving, military combat). To exemplify, the importance of contextual information in medical diagnosis has already been highlighted (McRobert et al., 2013; Verkoeijen et al., 2004). While tennis has therefore been used as a vehicle to examine the role of contextual information in expert anticipation, the novel findings presented in this thesis provide important theoretical and applied implications that advance knowledge and understanding of perceptual-cognitive expertise in multiple domains. As is the case with any research however, the body of research within this thesis has some limitations. These will be outlined in the next section, along with suggestions as to how researchers may account for some of these limitations in future research studies.

Limitations

A potential limitation of the approach taken throughout this thesis is the extent to which the experimental design represents the performance environment (Brunswik, 1956; Pinder, Davids, Renshaw, & Araújo, 2011a). Some researchers have suggested that the use of simulated laboratory-based tasks have often been limited by their failure to preserve the functional coupling between perception and action (e.g., Araújo, Davids, & Hristovski, 2006; van der Kamp et al., 2008). Others have suggested that the viewing perspective employed in some simulated laboratory-based tasks could evoke different processes than those underlying performance in situ (e.g., Dicks et al., 2010; Mann et al., 2009). The argument for designing a more representative task is based on the suggestion that maintenance of action fidelity (the similarity between the response in the task and in the performance environment) and functionality (the similarity between the constraints in the task and in the performance environment) is integral to capturing the action of interest (Pinder, Davids, Renshaw, & Araújo, 2011b). In this thesis, while there was a movement component to the response, the primary researcher recorded the verbal response and perception and action were decoupled. Additionally, a third person viewing perspective was employed along with manipulations to the visual display that removed some information that would normally be available in the environment. Collectively, this is likely to have resulted in sub-optimal levels of action fidelity and functionality.

Although the skill differences observed across the five studies provide construct validity for the approach taken in the thesis, it is important to strive towards the use of more representative tasks in future, to increase the likelihood of the findings being generalisable to the performance setting. However, when considering experimental design, it is also important to strike a balance between ecological validity, internal validity and experimental control (Causer, Barach, & Williams, 2014). In recent years, more representative tasks have been employed to examine expert anticipation (e.g., Dicks et al., 2010; Ranganathan & Carlton, 2007). While these attempts to maintain high levels of action fidelity and functionality are admirable, it is unlikely that all of the aims of this thesis could have been achieved through the use of such experimental designs. Potential problems include between-trials variability (the aforementioned studies involved less dynamic tasks than the studies in this thesis) and controlling the presentation of pertinent postural cues. One particularly promising platform from which to continue this line of research could be through the use of virtual reality technology (Bideau et al., 2010; Brault, Bideau, Kulpa, & Craig, 2012; Correia, Araújo, Cummins, & Craig, 2012). Given the decreasing costs associated with virtual reality systems (Cummins & Craig, 2016), this approach appears to offer the potential to strike a balance between internal control and ecological validity. Importantly, it would permit a more representative viewing perspective to be employed and the maintenance of functional perception-action coupling.

An interesting observation arising from the change in screen size in Study 5 compared to the other studies is that very similar trends emerged. Regardless of screen size, skilled participants were more accurate than less-skilled counterparts and response accuracy was higher when viewing videos than animations. This observation supports research suggesting that screen size does not affect performance on perceptual-cognitive tasks (Spittle, Kremer, & Hamilton, 2010). This is an important methodological issue as great effort and money is spent attempting to create more ecologically valid testing environments through the use of large screens. Indeed, it is surprising that researchers strive to create such conditions in the laboratory when so few studies have been conducted to investigate the effect of screen size on performance in the first place (for exceptions see Al-Abood, Bennett, Hernandez, Ashford, & Davids, 2002; Spittle et al., 2010). Equally, the change in response mode in Study 5 compared to the earlier studies did not appear to affect the results. This finding is less useful however, as neither response maintained the link between perception and action. Previous research highlighting more pronounced skill-based performance differences as a result of response mode have demonstrated advantages of perception-action coupled over uncoupled conditions (e.g., Farrow & Abernethy, 2003; Mann et al., 2010).

Although the findings of this thesis suggest that the ability to use contextual and postural information to anticipate an opponent's intentions is due to perceptual-cognitive adaptations resulting from experience and practice, the acquisition processes which lead to the development of the skills facilitating superior performance were not investigated. Practice history profile data has previously been collected to identify developmental activities which lead to superior anticipation and decision making (Ford, Low, McRobert, & Williams, 2010; Roca et al., 2012). For example, Roca et al. (2012) observed that the amount of time spent in soccer-specific play activities during childhood was a strong predictor of performance on an anticipation and decision making task. The authors speculated that time spent in domain-specific play provides players the opportunity to engage in activities that promote anticipation and decision making, resulting in perceptual-cognitive adaptations. While the alternative approach to examining how perceptual-cognitive expertise is developed is to conduct learning studies, most studies to date have focused on determining whether the development of skills needed to pick-up and utilise postural cues can be fast-tracked through video simulation or field-based training interventions (Abernethy et al., 2012; Smeeton, Williams, Hodges, & Ward, 2005; Williams et al., 2002). However, it would be of further benefit to conduct similar investigations to determine whether training interventions can be used to develop the perceptual-cognitive skills needed to effectively pick up and utilise contextual information during anticipation and to examine the practice conditions needed to do so.

Broadbent, Ford, O'Hara, Williams, and Causer (2017) conducted a learning study to determine if having access to contextual information during anticipation training aids the learning process. Intermediate-level tennis players took part in a video simulation training programme in which the footage being viewed either presented the preceding shot sequence in the order the shots had been played in the recorded rally or in a jumbled order prior to the occluded shot, thus providing or omitting contextual information respectively. Each group displayed improvements in the condition they had trained in from pre-test to retention test. However, the group that trained with contextual information available from the correctly ordered shot sequence became more efficient when anticipating the opponent's intentions in a field-based transfer test, whereas the group that trained without contextual information did not. It therefore appears to be possible to train the perceptual-cognitive skills needed to pick up and use contextual information to anticipate more effectively. However, this study is a rarity in the research literature with much more research needed to adequately inform applied practice.

While some limitations of the thesis are therefore evident, the opportunity exists for further research to confirm and extend these findings in more representative tasks in sport and other domains as well as further research investigating the acquisition processes leading to the development of expert anticipation. Having discussed the findings and implications of the thesis and potential limitations of the research, the next section will be used to highlight the outstanding issues that need to be addressed to inform the development of an overarching theoretical framework of expert anticipation.

Informing the development of an overarching theoretical framework

Cañal-Bruland and Mann (2015, p. 3) stated "We hope that a solid understanding of contextual information sources will lead to the development of an overarching theoretical framework that can predict and explain anticipatory behaviour…" While this statement highlights an admirable goal towards which all researchers interested in this topic should ideally strive, and is a goal that, if achieved, would benefit the field enormously, it does not fully account for the complexity of the task. As it stands there exist a myriad of factors which need to be much more thoroughly researched and understood to reliably inform the development of such a model.

First, the contextual information presented and manipulated in this thesis was delimited to the sequential relative movements and final positioning of the players and the ball. These sources are likely to make up only a small portion of the contextual information available in the performance environment at any given time. In particular, the focus of this thesis has been on investigating general contextual information sources rather than opponent-specific context (e.g., action tendencies [Mann et al., 2014]). While there is limited evidence of how the use of these two broad information sources may differ, early findings suggest that the relative use of these information sources may vary over the course of an encounter with an opponent (Schläppi-Lienhard & Hossner, 2015). Moreover, given the number of different sources of contextual information that are available at any one time (e.g., shot sequencing, player positioning, score, opponent action tendencies), it is likely that the importance of each of these sources differs over the course of an action sequence. However, the usefulness and prioritisation of various contextual information sources over time is yet to be explored.

Second, a model of anticipation should highlight and explain the potential temporal interaction between the use of contextual and postural information sources. One particularly positive aspect of Müller and Abernethy's (2012) model of anticipation in striking sports is that it provides an initial indication of the timeline of information pick-up in anticipation, suggesting a potential shift from the use of contextual to postural information as the opponent's movement pattern evolves. However, the model does not account for the multiple sources of contextual information that may influence anticipation at any given time and the extent to which their importance and impact on anticipation may vary in the lead-up to the critical event. Moreover the temporal interaction between contextual and postural information in the lead-up to the critical event is not sufficiently detailed. While an initial attempt was made in this thesis to determine how postural cues are integrated with readily available contextual information, the methods employed did not permit the timeline of the potential integration of information to be fully examined. It appears, from the findings of Study 5 in particular, that expert performers generate initial expectations based on contextual information such as the preceding shot sequence and player movements before adjusting these expectations as pertinent postural cues become available (see also Gredin, Broadbent, Bishop, & Williams, 2017; Loffing & Hagemann, 2014). However, further research is required to determine how the expectations of expert performers develop as a function of time and information available.

Third, in addition to the previous point, the congruence effect recently highlighted by several researchers would need to be fully accounted for (e.g., Gredin et al., 2017; Loffing et al., 2015; Mann et al., 2014). While initial findings suggested that the use of contextual information in the formation of expectations is only beneficial when this information is congruent with the outcome and detrimental if not, more recent findings suggest that skilled performers can resolve this detrimental effect by prioritising relevant information sources as they become available (Gredin et al., 2017). This notion is supported by the findings of Study 5, in which skilled participants generated less options when postural cues were available in addition to contextual information, suggesting the potential prioritisation of postural cues over contextual information when available. Nevertheless, our knowledge of this process is limited. In particular, more research is needed to tease out the underlying perceptual-cognitive processes that may facilitate this information prioritisation. Moreover, whether congruence effects are observed over prolonged periods of time needs further investigation.

Fourth, while it was outside the remit of this thesis to consider how an opponent's use of disguise or deception may affect anticipation, a theoretical model of anticipation should account for these factors. There exists a reasonable body of research to demonstrate that athletes can intentionally present the opponent with misleading postural information (e.g., Brault et al., 2012; Jackson et al., 2006; Rowe et al., 2012). With particular relevance to this thesis, contextual information may be more heavily relied upon if an opponent has a particular tendency to use disguise and deception, as this may result in a lack of available reliable postural cues. To date however, there appears to be very little published research that has investigated the potential interaction between deception/disguise and the prioritisation of information sources, and importantly, how this impacts anticipation (for an exception, see Barton, Jackson, & Bishop, 2013).

Finally, while the findings of this thesis and other recent studies highlight the importance of being able to utilise various sources of information to anticipate an opponent's intentions, a more complete account of expert anticipation would also explain how skilled athletes do so under various stressors (e.g., anxiety, fatigue). Most research that has manipulated these stressors has, thus far, done so to determine their effects on anticipation and decision making without considering the different sources of information that may be available to performers in real-world situations (e.g., Casanova et al., 2013; Vater, Roca, & Williams, 2015; Williams & Elliott, 1999). Conversely, research on how anxiety may affect and/or induce the use of different information sources during anticipation is scarce (for exceptions see Cocks et al., 2015; Runswick et al., 2017). While the findings of Cocks et al. (2015), for example, appear to suggest that the information relied upon during anticipation is at least somewhat shaped by the degree of anxiety involved in the situation, more research is needed to examine the various effects and interactions that may be evident as a result of the presence of such stressors that are so common at the highest levels of sporting performance.

To summarise, while our knowledge of how contextual information influences anticipation is increasing, considering the complex nature of anticipation and the multiple influencing factors, extending existing models or indeed creating new models of anticipation is not a trivial task. However, the increasing interest in this area is tremendously encouraging to the point that most of these outstanding issues may be quickly addressed, bringing us significantly closer to the development of an overarching theoretical framework.

Concluding remarks

To conclude, by highlighting the important role of contextual information in anticipation, this thesis has furthered knowledge and understanding in an area of the expertise literature that has received surprisingly little research attention to date (Cañal-Bruland & Mann, 2015). Specifically, the thesis used a novel approach to confirm and extend previous research suggesting that skilled performers can use contextual information to anticipate effectively in advance of pertinent postural cues becoming available. Moreover, the expert advantage in picking up and integrating pertinent postural cues with readily available contextual information was highlighted. The thesis further added to existing knowledge by investigating the specific sources of contextual information used to anticipate effectively. To this end, the preceding sequence of events and the relative movements and positioning of the players appear to provide particularly useful contextual information for anticipating the opponent's intentions. Moreover, skilled performers also appear to be able to integrate several sources of contextual information in a way that facilitates conscious access to relevant information from LTM to anticipate accurately. Finally, the thesis extended previous research suggesting that expert anticipation is underpinned by the cognitive mechanisms proposed by LTWM theory. Findings suggest that skilled performers possess more elaborate domain-specific memory representations which allow for greater evaluation of the presented information, access to relevant potential alternative outcomes and ultimately facilitate more accurate anticipation than can be achieved by less-skilled counterparts. Nevertheless, when more reliable, pertinent postural cues are available, cognitive mechanisms involving the consideration of fewer options may be optimal (e.g., as proposed by the Take The First heuristic).

When faced with the extreme time constraints evident in fast ball sports, waiting for pertinent postural cues to become available may not be a feasible option. The findings of the thesis highlight that contextual information can facilitate anticipation in advance of pertinent postural cues becoming available and the ability to use this information to anticipate effectively is due to perceptual-cognitive adaptations resulting from experience and practice. An abundance of theoretical and practical implications are evident. Having highlighted the importance of contextual information for anticipation, the findings of this thesis will ultimately lead to further research in the area. Potentially, with time, as the knowledge base extends and more researchers commit to investigating this relatively nascent, yet highly important research area, the goal of developing an overarching framework of anticipation may be achieved.

References

Abernethy, B. (1987). Selective attention in fast ball sports. II: Expert novice differences. *Australian Journal of Science and Medicine in Sport, 19*, 7-16.

Abernethy, B. (1990). Expertise, visual search, and information pick-up in squash. *Perception, 19*, 63-77.

Abernethy, B., Gill, D. P., Parks, S. L., & Packer, S. T. (2001). Expertise and the perception of kinematic and situational probability information. *Perception, 30*, 233-252.

Abernethy, B., Neal, R. J., & Koning, P. (1994). Visual–perceptual and cognitive differences between expert, intermediate, and novice snooker players. *Applied Cognitive Psychology, 8*, 185-211.

Abernethy, B., & Russell, D. G. (1987). The relationship between expertise and visual search strategy in a racquet sport. *Human Movement Science, 6*, 283-319.

Abernethy, B., Schorer, J., Jackson, R. C., & Hagemann, N. (2012). Perceptual training methods compared: The relative efficacy of different approaches to enhancing sport-specific anticipation. *Journal of Experimental Psychology: Applied, 18*, 143-153.

Abernethy, B., & Wollstein, J. (1989). Improving anticipation in racquet sports. *Sports Coach, 12*, 15-18.

Abernethy, B., & Zawi, K. (2007). Pickup of essential kinematics underpins expert perception of movement patterns. *Journal of Motor Behavior, 39*, 353-367.

Abernethy, B., Zawi, K., & Jackson, R. C. (2008). Expertise and attunement to kinematic constraints. *Perception, 37,* 931-948.

Ackerman, P. L. (1988). Determinants of individual differences during skill acquisition: Cognitive abilities and information processing. *Journal of Experimental Psychology: General, 117*, 288-318.

Adelson, B. (1981). Problem solving and the development of abstract categories in programming languages. *Memory & Cognition, 9*, 422-433.

Afonso, J., Garganta, J., McRobert, A., Williams, A. M., & Mesquita, I. (2012). The perceptual cognitive processes underpinning skilled performance in volleyball: Evidence from eye-movements and verbal reports of thinking involving an in situ representative task. *Journal of Sports Science & Medicine, 11*, 339-345.

Afonso, J., & Mesquita, I. (2013). Skill-based differences in visual search behaviours and verbal reports in a representative film-based task in volleyball. *International Journal of Performance Analysis in Sport, 13*, 669-677.

Al-Abood, S. A., Bennett, S. J., Hernandez, F. M., Ashford, D., & Davids, K. (2002). Effect of verbal instructions and image size on visual search strategies in basketball free throw shooting. *Journal of Sports Sciences*, *20*, 271-278.

Alain, C., & Proteau, L. (1977). Perception of objective probabilities in motor performance. In B. Kerr (Ed.), *Human Performance and Behaviour* (p. 1-5). Banff, Alberta.

Alain, C., & Proteau, L. (1978). Etude des variables relatives au traitement de l’information en sport de raquette. *Canadian Journal of Applied Sport Sciences, 3*, 27-35.

Alder, D., Ford, P. R., Causer, J., & Williams, A. M. (2014). The coupling between gaze behavior and opponent kinematics during anticipation of badminton shots. *Human Movement Science, 37,* 167-179.

Allard, F., Graham, S., & Paarsalu, M. E. (1980). Perception in sport: Basketball. *Journal of Sport Psychology, 2*, 14-21.

Anderson, J. R. (1987). Methodologies for studying human knowledge. *Behavioral and Brain Sciences, 10*, 467-505.

Anderson, J. R. (1990). *Cognitive psychology and its implications*. WH Freeman/Times Books/Henry Holt & Co.

Applegate, R. A., & Applegate, R. A. (1992). Set shot shooting performance and visual acuity in basketball. *Optometry and Vision Science, 69*, 765-768.

Araújo, D., Davids, K., & Hristovski, R. (2006). The ecological dynamics of decision making in sport. *Psychology of Sport and Exercise, 7,* 653-676.

Baker, J., & Farrow, D. (2015). *Routledge handbook of sport expertise*. Oxon: Routledge.

Barton, H., Jackson, R. C., & Bishop, D. (2013). Knowledge of player tendencies: The effect on anticipation skill and susceptibility to deception. *Journal of Sport & Exercise Psychology, 35*, S18.

Belling, P. K., Suss, J., & Ward, P. (2015a). Advancing theory and application of cognitive research in sport: Using representative tasks to explain and predict skilled anticipation, decision-making, and option-generation behavior. *Psychology of Sport and Exercise, 16,* 45-59.

Belling, P. K., Suss, J., & Ward, P. (2015b). The effect of time constraint on anticipation, decision making, and option generation in complex and dynamic environments. *Cognition, Technology & Work, 17,* 355-366.

Belling, P. K., & Ward, P. (2015). Time to start training: A review of cognitive research in sport and bridging the gap from academia to the field. *Procedia Manufacturing*, *3*, 1219-1224.

Bideau, B., Kulpa, R., Vignais, N., Brault, S., Multon, F., & Craig, C. (2010). Using virtual reality to analyze sports performance. *IEEE Computer Graphics and Applications, 30*, 14-21.

Bloom, B. S. (1985). *Developing Talent in Young People*. New York: Ballantine.

Bourne, M., Bennett, S. J., Hayes, S. J., Smeeton, N. J., & Williams, A. M. (2013). Information underpinning anticipation of goal-directed throwing. *Attention, Perception, & Psychophysics, 75,* 1559-1569.

Brault, S., Bideau, B., Kulpa, R., & Craig, C. M. (2012). Detecting deception in movement: The case of the side-step in rugby. *PloS One, 7,* e37494.

Broadbent, D. P., Causer, J., Ford, P. R., & Williams, A. M. (2015). Contextual interference effect on perceptual-cognitive skills training. *Medicine and Science in Sports and Exercise, 47*, 1243-1250.

Broadbent, D. P., Ford, P. R., O'Hara, D. A., Williams, A. M., & Causer, J. (2017). The effect of a sequential structure of practice for the training of perceptual-cognitive skills in tennis. *PloS One, 12,* e0174311.

Brunswik, E. (1956). *Perception and the representative design of psychological experiments* (2nd ed.). Berkeley, CA: University of California Press.

Buckolz, E., Prapavesis, H., & Fairs, J. (1988). Advance cues and their use in predicting tennis passing shots. *Canadian Journal of Sport Sciences, 13,* 20-30.

Cañal-Bruland, R., Filius, M. A., & Oudejans, R. R. D. (2015). Sitting on a fastball. *Journal of Motor Behaviour, 47,* 267-270.

Cañal-Bruland, R., & Mann, D. L. (2015). Time to broaden the scope of research on anticipatory behavior: A case for the role of probabilistic information. *Frontiers in Psychology, 6*.

Cañal-Bruland, R., van Ginneken, W. F., van der Meer, B. R., & Williams, A. M. (2011). The effect of local kinematic changes on anticipation judgments. *Human Movement Science, 30,* 495-503.

Cañal-Bruland, R., & Williams, A. M. (2010). Recognizing and predicting movement effects. *Experimental Psychology, 57,* 320-326.

Casanova, F., Garganta, J., Silva, G., Alves, A., Oliveira, J., & Williams, A. M. (2013). Effects of prolonged intermittent exercise on perceptual-cognitive processes. *Medicine & Science in Sports & Exercise, 45,* 1610-1617.

Catteeuw, P., Gilis, B., Wagemans, J., & Helsen, W. (2010). Perceptual-cognitive skills in offside decision making: Expertise and training effects. *Journal of Sport and Exercise Psychology, 32,* 828-844.

Causer, J., Barach, P., & Williams, A. M. (2014). Expertise in medicine: Using the expert performance approach to improve simulation training. *Medical Education, 48*, 115-123.

Causer, J., Smeeton, N. J., & Williams, A. M. (2017). Expertise differences in anticipatory judgements during a temporally and spatially occluded task. *PloS One, 12*, e0171330.

Chan, C. (1992). *Implicit Cognitive Processes: Theoretical Issues and Applications in Computer Systems Design.* Unpublished doctoral dissertation, University of Oxford, England.

Charness, N. (1976). Memory for chess positions: Resistance to interference. *Journal of Experimental Psychology: Human Learning and Memory, 2*, 641-653.

Chase, W. G., & Simon, H. A. (1973). Perception in chess. *Cognitive Psychology, 4*, 55-81.

Cocks, A. J., Jackson, R. C., Bishop, D. T., & Williams, A. M. (2015). Anxiety, anticipation and contextual information: A test of attentional control theory. *Cognition and Emotion, 30*, 1037-1048.

Correia, V., Araújo, D., Cummins, A., & Craig, C. M. (2012). Perceiving and acting upon spaces in a VR rugby task: Expertise effects in affordance detection and task achievement. *Journal of Sport and Exercise Psychology, 34*, 305-321.

Croft, J. L., Button, C., & Dicks, M. (2010). Visual strategies of sub-elite cricket batsmen in response to different ball velocities. *Human Movement Science, 29*, 751-763.

Crognier, L., & Féry, Y. (2005). Effect of tactical initiative on predicting passing shots in tennis. *Applied Cognitive Psychology, 19*, 637-649.

Crognier, L., & Féry, Y. (2007). 40 ans de recherches sur l'anticipation en tennis: Une revue critique [40 years of research on anticipation in tennis: A critical review]. *Movement & Sport Sciences, 3*, 9-35.

Cummins, A., & Craig, C. (2016). Design and implementation of a low cost virtual rugby decision making interactive. *International Conference on Augmented Reality, Virtual Reality and Computer Graphics*, 16-32.

Davids, K., Button, C., & Bennett, S. J. (2008). *Dynamics of skill acquisition: A constraints-led approach*. Champaign, IL: Human Kinetics.

De Groot, A. D. (1965). *Thought and choice in chess*. The Hague: Mouton.

Dicks, M., Button, C., & Davids, K. (2010). Examination of gaze behaviors under in situ and video simulation task constraints reveals differences in information pickup for perception and action. *Attention, Perception, & Psychophysics, 72*, 706-720.

Eccles, D. (2012). Verbal reports of cognitive processes. In G. Tenenbaum, R. C. Ecklund, & A. Kamata (Eds.), *Handbook of Measurement in Sport and Exercise Psychology* (pp. 103-117). Champaign, IL: Human Kinetics.

Egan, D. E., & Schwartz, B. J. (1979). Chunking in recall of symbolic drawings. *Memory & Cognition, 7*, 149-158.

Ericsson, K. A., & Crutcher, R. (1990). The nature of exceptional performance. In P. B. Baltes, D. L. Featherman, & R. M. Lerner (Eds.), *Lifespan Development and Behaviour* (Vol. 10, pp. 187-217). Hillside, NJ: Erlbaum.

Ericsson, K. A., & Kintsch, W. (1995). Long-term working memory. *Psychological Review, 102*, 211-245.

Ericsson, K. A., & Kirk, E. (2001). *Instructions for giving retrospective verbal reports*. Tallahassee, FL: Florida State University.

Ericsson, K. A., Krampe, R. T., & Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review, 100,* 363-406.

Ericsson, K. A., Patel, V., & Kintsch, W. (2000). How experts' adaptations to representative task demands account for the expertise effect in memory recall: Comment on Vicente and Wang (1998). *Psychological Review, 107*, 578-592.

Ericsson, K. A., & Simon, H. A. (1980). Verbal reports as data. *Psychological Review, 87*, 215-251.

Ericsson, K. A., & Simon, H. A. (1993). *Protocol analysis: Verbal reports as data* (rev. ed.). Cambridge, MA: Bradford Books/MIT Press.

Ericsson, K. A., & Smith, J. (1991). Prospects and limits of the empirical study of expertise: An introduction. In K. A. Ericsson & J. Smith (Eds.), *Toward a general theory of expertise: Prospects and limits* (pp. 1-38). New York, NY: Cambridge University Press.

Ericsson, K. A., & Ward, P. (2007). Capturing the naturally occurring superior performance of experts in the laboratory: Toward a science of expert and exceptional performance. *Current Directions in Psychological Science, 16*, 346-350.

Farrow, D., & Abernethy, B. (2003). Do expertise and the degree of perception—action coupling affect natural anticipatory performance?. *Perception, 32*, 1127-1139.

Farrow, D., & Abernethy, B. (2015). Expert anticipation and pattern recognition. In J. Baker & D. Farrow (Eds.), *Routledge Handbook of Sport Expertise* (pp. 9-21). Oxon: Routledge.

Farrow, D., & Reid, M. (2012). The contribution of situational probability information to anticipatory skill. *Journal of Science and Medicine in Sport, 15,* 368-373.

Farrow, D., Reid, M., Buszard, T., & Kovalchik, S. (2017). Charting the development of sport expertise: Challenges and opportunities. *International Review of Sport and Exercise Psychology,* 1-20.

Fleishman, E. A. (1972). On the relation between abilities, learning, and human performance. *American Psychologist, 27,* 1017-1032.

Ford, P. R., Low, J., McRobert, A. P., & Williams, A. M. (2010). Developmental activities that contribute to high or low performance by elite cricket batters when recognizing type of delivery from bowlers' advanced postural cues. *Journal of Sport and Exercise Psychology, 32*, 638-654.

Frey, P. W., & Adesman, P. (1976). Recall memory for visually presented chess positions. *Memory & Cognition, 4*, 541-547.

Fullerton, H. S. (1921). Why Babe Ruth is greatest home-run hitter. *Popular Science Monthly, 99*, 19-21.

Galton, F. (1869). *Hereditary genius: An inquiry into its laws and consequences*. London: Macmillan.

Gilhooly, K. J., Wood, M., Kinnear, P. R., & Green, C. (1988). Skill in map reading and memory for maps. *The Quarterly Journal of Experimental Psychology, 40,* 87-107.

Gillet, E., Leroy, D., Thouvarecq, R., & Stein, J. (2009). A notational analysis of elite tennis serve and serve-return strategies on slow surface. *Journal of Strength and Conditioning Research, 23*, 532-539.

Goldin, S. E. (1978). Effects of orienting tasks on recognition of chess positions. *The American Journal of Psychology, 91*, 659-671.

Goldin, S. E. (1979). Recognition memory for chess positions: Some preliminary research. *The American Journal of Psychology, 92*, 19-31.

Gorman, A. D., Abernethy, B., & Farrow, D. (2011). Investigating the anticipatory nature of pattern perception in sport. *Memory & Cognition, 39*, 894-901.

Gorman, A. D., Abernethy, B., & Farrow, D. (2012). Classical pattern recall tests and the prospective nature of expert performance. *The Quarterly Journal of Experimental Psychology, 65*, 1151-1160.

Gorman, A. D., Abernethy, B., & Farrow, D. (2013). Is the relationship between pattern recall and decision-making influenced by anticipatory recall? *The Quarterly Journal of Experimental Psychology, 66*, 2219-2236.

Gorman, A. D., Abernethy, B., & Farrow, D. (2015). Evidence of different underlying processes in pattern recall and decision-making. *The Quarterly Journal of Experimental Psychology, 68*, 1813-1831.

Gottsdanker, R., & Kent, K. (1978). Reaction time and probability on isolated trials. *Journal of Motor Behavior, 10*, 233-238.

Goulet, C., Bard, C., & Fleury, M. (1989). Expertise differences in preparing to return a tennis serve: A visual information-processing approach. *Journal of Sport & Exercise Psychology, 11*, 382-398.

Gray, R. (2002a). Behavior of college baseball players in a virtual batting task. *Journal of Experimental Psychology: Human Perception and Performance, 28*, 1131-1148.

Gray, R. (2002b). "Markov at the bat": A model of cognitive processing in baseball batters. *Psychological Science, 13*, 542-547.

Gray, R. (2015). The moneyball problem: What is the best way to present situational statistics to an athlete? *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 59*, 1377-1381.

Gredin, V. G., Bishop, D. T., Broadbent, D. P., & Williams, A. M. (2017). Anticipating the intentions of others: The impact of probabilistic information, *22nd Annual Congress of the European College of Sport Science*.

Hagemann, N., Schorer, J., Cañal-Bruland, R., Lotz, S., & Strauss, B. (2010). Visual perception in fencing: Do the eye movements of fencers represent their information pickup? *Attention, Perception, & Psychophysics, 72*, 2204-2214.

Helsen, W. F., & Starkes, J. L. (1999). A multidimensional approach to skilled perception and performance in sport. *Applied Cognitive Psychology, 13,* 1-27.

Hick, W. E. (1952). On the rate of gain of information. *The Quarterly Journal of Experimental Psychology, 4,* 11-26.

Hoffman, R. R., Ward, P., Feltovich, P. J., DiBello, L., Fiore, S. M., & Andrews, D. H. (2014). *Accelerated expertise: Training for high proficiency in a complex world* New York, NY: Psychology Press.

Hopwood, M. J., Mann, D. L., Farrow, D., & Nielsen, T. (2011). Does visual-perceptual training augment the fielding performance of skilled cricketers?. *International Journal of Sports Science & Coaching, 6*, 523-535.

Huys, R., Cañal-Bruland, R., Hagemann, N., Beek, P. J., Smeeton, N. J., & Williams, A. M. (2009). Global information pickup underpins anticipation of tennis shot direction. *Journal of Motor Behavior*, *41*, 158-170.

Jackson, R. C., & Mogan, P. (2007). Advance visual information, awareness, and anticipation skill. *Journal of Motor Behavior, 39,* 341-351.

Jackson, R. C., Warren, S., & Abernethy, B. (2006). Anticipation skill and susceptibility to deceptive movement. *Acta Psychologica, 123,* 355-371.

Johansson, G. (1973). Visual perception of biological motion and a model for its analysis. *Perception & Psychophysics, 14,* 201-211.

Johnson, J. G., & Raab, M. (2003). Take the first: Option-generation and resulting choices. *Organizational Behavior and Human Decision Processes, 91,* 215-229.

Jones, C., & Miles, T. (1978). Use of advance cues in predicting the flight of a lawn tennis ball. *Journal of Human Movement Studies, 4*, 231-235.

Klein, G. A. (1993). A recognition-primed decision (RPD) model of rapid decision making. In G. A. Klein, J. Orasanu, R. Calderwood, & C. E. Zsambok (Eds.), *Decision Making in Action: Models and* Methods (pp.138-147). Norwood, NJ: Ablex Publishing Corporation.

Klein, G. A., Calderwood, R., & Clinton-Cirocco, A. (1986). Rapid decision making on the fire ground. In *Proceedings of the Human Factors and Ergonomics Society 30th Annual Meeting* (Vol. 1, pp. 576-580). Norwood, NJ: Ablex Publishing Corporation.

Klein, G. A., & Peio, K. J. (1989). Use of a prediction paradigm to evaluate proficient decision making. *The American Journal of Psychology, 102*, 321-331.

Kozlowski, L. T., & Cutting, J. E. (1977). Recognizing the sex of a walker from a dynamic point-light display. *Perception & Psychophysics, 21*, 575-580.

Krupinski, E. A. (2000). The importance of perception research in medical imaging. *Radiation Medicine, 18*, 329-334.

Kunde, W., Skirde, S., & Weigelt, M. (2011). Trust my face: Cognitive factors of head fakes in sports. *Journal of Experimental Psychology: Applied, 17*, 110-127.

Laborde, S., & Raab, M. (2013). The tale of hearts and reason: The influence of mood on decision making. *Journal of Sport and Exercise Psychology, 35*, 339-357.

Loffing, F., & Cañal-Bruland, R. (2017). Anticipation in sport. *Current Opinion in Psychology, 16*, 6-11.

Loffing, F., & Hagemann, N. (2014). On-court position influences skilled tennis players' anticipation of shot outcome. *Journal of Sport & Exercise Psychology, 36*, 14-26.

Loffing, F., Sölter, F., Hagemann, N., & Strauss, B. (2016). On-court position and handedness in visual anticipation of stroke direction in tennis. *Psychology of Sport and Exercise, 27*, 195-204.

Loffing, F., Stern, R., & Hagemann, N. (2015). Pattern-induced expectation bias in visual anticipation of action outcomes. *Acta Psychologica, 161*, 45-53.

Loffing, F., Wilkes, T., & Hagemann, N. (2011). Skill level and graphical detail shape perceptual judgments in tennis. *Perception, 40*, 1447-1456.

Mann, D. L., Abernethy, B., & Farrow, D. (2010a). Visual information underpinning skilled anticipation: The effect of blur on a coupled and uncoupled in situ anticipatory response. *Attention, Perception, & Psychophysics, 72*, 1317-1326.

Mann, D. L., Abernethy, B., & Farrow, D. (2010b). The resilience of natural interceptive actions to refractive blur. *Human Movement Science, 29*, 386-400.

Mann, D. L., Farrow, D., Shuttleworth, R., & Hopwood, M. (2009). The influence of viewing perspective on decision-making and visual search behaviour in an invasive sport. *International Journal of Sport Psychology, 40*, 546-564.

Mann, D. L., Ho, N. Y., De Souza, N. J., Watson, D. R., & Taylor, S. J. (2007). Is optimal vision required for the successful execution of an interceptive task? *Human Movement Science, 26*, 343-356.

Mann, D., & Savelsbergh, G. (2015). Issues in the measurement of anticipation. In J. Baker & D. Farrow (Eds.), *Routledge Handbook of Sport Expertise* (pp. 166-175). Oxon: Routledge.

Mann, D. L., Schaefers, T., & Cañal-Bruland, R. (2014). Action preferences and the anticipation of action outcomes. *Acta Psychologica, 152*, 1-9.

Mann, D. T. Y., Williams, A. M., Ward, P., & Janelle, C. M. (2007). Perceptual-cognitive expertise in sport: A meta-analysis. *Journal of Sport & Exercise Psychology, 29*, 457-478.

Marteniuk, R. G. (1976). *Information processing in motor skills*. New York, NY: Holt, Rinehart, & Winston.

McGarry, T., & Franks, I. M. (1996). In search of invariant athletic behaviour in sport: An example from championship squash match-play. *Journal of Sports Sciences, 14*, 445-456.

McKenna, F. P., & Horswill, M. S. (1999). Hazard perception and its relevance for driver licensing. *Journal of International Association of Traffic and Safety Sciences, 23*, 36-41.

McLeod, P., & Land, M. F. (2000). From eye movements to actions: How batsmen hit the ball. *Nature Neuroscience, 3*, 1340-1345.

McPherson, S. L. (1999). Tactical differences in problem representations and solutions in collegiate varsity and beginner female tennis players. *Research Quarterly for Exercise and Sport, 70,* 369-384.

McPherson, S. L. (2000). Expert-novice differences in planning strategies during collegiate singles tennis competition. *Journal of Sport and Exercise Psychology, 22*, 39-62.

McPherson, S. L., & Kernodle, M. (2007). Mapping two new points on the tennis expertise continuum: Tactical skills of adult advanced beginners and entry-level professionals during competition. *Journal of Sports Sciences, 25*, 945-959.

McRobert, A. P., Causer, J., Vassiliadis, J., Watterson, L., Kwan, J., & Williams, A. M. (2013). Contextual information influences diagnosis accuracy and decision making in simulated emergency medicine emergencies. *BMJ Quality & Safety, 22*, 478-484.

McRobert, A. P., Ward, P., Eccles, D. W., & Williams, A. M. (2011). The effect of manipulating context-specific information on perceptual-cognitive processes during a simulated anticipation task. *British Journal of Psychology, 102*, 519-534.

McRobert, A., Williams, A. M., Ward, P., & Eccles, D. (2009). Tracing the process of expertise in a simulated anticipation task. *Ergonomics*, *52*, 474-483.

Mecheri, S., Rioult, F., Mantel, B., Kauffmann, F., & Benguigui, N. (2016). The serve impact in tennis: First large-scale study of big Hawk-Eye data. *Statistical Analysis and Data Mining: The ASA Data Science Journal, 9,* 310-325.

Milazzo, N., Farrow, D., Ruffault, A., & Fournier, J. F. (2015). Do karate fighters use situational probability information to improve decision-making performance during on-mat tasks? *Journal of Sports Sciences, 34*, 1547-1556.

Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review, 63*, 81-97.

Moore, G. C., & Müller, S. (2014). Transfer of expert visual anticipation to a similar domain. *The Quarterly Journal of Experimental Psychology, 67,* 186-196.

Moran, A. (2009). Cognitive psychology in sport: Progress and prospects. *Psychology of Sport and Exercise, 10*, 420-426.

Müller, S., & Abernethy, B. (2012). Expert anticipatory skill in striking sports: A review and a model. *Research Quarterly for Exercise and Sport, 83*, 175-187.

Müller, S., Abernethy, B., Eid, M. McBean, R., & Rose, M. (2010). Expertise and the spatio-temporal characteristics of anticipatory information pick-up from complex movement patterns. *Perception*, *39,* 745-760.

Müller, S., Abernethy, B., & Farrow, D. (2006). How do world-class cricket batsmen anticipate a bowler's intention? *The Quarterly Journal of Experimental Psychology, 59*, 2162-2186.

Murphy, C. P., Jackson, R. C., Cooke, K., Roca, A., Benguigui, N., & Williams, A. M. (2016). Contextual information and perceptual-cognitive expertise in a dynamic, temporally-constrained task. *Journal of Experimental Psychology: Applied, 22,* 455-470.

Navia, J. A., van der Kamp, J., & Ruiz, L. M. (2013). On the use of situational and body information in goalkeeper actions during a soccer penalty kick. *International Journal of Sport Psychology, 44*, 234-251.

Newell, K. M. (1986). Constraints on the development of coordination. In M. G. Wade & H. T. A. Whiting (Eds.), *Motor Skill Acquisition in Children: Aspects of Coordination and Control* (pp. 341-360). Amsterdam: Martinus Nijhoff.

North, J. S., Hope, E., & Williams, A. M. (2016). The relative importance of different perceptual-cognitive skills during anticipation. *Human Movement Science, 49,* 170-177.

North, J. S., Ward, P., Ericsson, K. A., & Williams, A. M. (2011). Mechanisms underlying skilled anticipation and recognition in a dynamic and temporally constrained domain. *Memory, 19*, 155-168.

North, J. S., Williams, A. M., Hodges, N., Ward, P., & Ericsson, K. A. (2009). Perceiving patterns in dynamic action sequences: Investigating the processes underpinning stimulus recognition and anticipation skill. *Applied Cognitive Psychology, 23,* 878-894.

Oxford Dictionaries (n.d.). Context. Retrieved from http://www.oxforddictionaries.com/definition/english/context

Paull, G., & Glencross, D. (1997). Expert perception and decision making in baseball. *International Journal of Sport Psychology, 28*, 35-56.

Pinder, R. A., Davids, K., Renshaw, I., & Araújo, D. (2011a). Representative learning design and functionality of research and practice in sport. *Journal of Sport and Exercise Psychology, 33,* 146-155.

Pinder, R. A., Davids, K., Renshaw, I., & Araújo, D. (2011b). Manipulating informational constraints shapes movement reorganization in interceptive actions. *Attention, Perception, & Psychophysics, 73,* 1242-1254.

Raab, M., & Johnson, J. G. (2007). Expertise-based differences in search and option-generation strategies. *Journal of Experimental Psychology: Applied, 13,* 158-170.

Ranganathan, R., & Carlton, L. G. (2007). Perception-action coupling and anticipatory performance in baseball batting. *Journal of Motor Behavior, 39,* 369-380.

Regan, D. (1997). Visual factors in hitting and catching. *Journal of Sports Sciences, 15,* 533-558.

Renshaw, I., & Fairweather, M. M. (2000). Cricket bowling deliveries and the discrimination ability of professional and amateur batters. *Journal of Sports Sciences, 18,* 951-957.

Ripoll, H., Kerlirzin, Y., Stein, J., & Reine, B. (1995). Analysis of information processing, decision making, and visual strategies in complex problem solving sport situations. *Human Movement Science, 14,* 325-349.

Roca, A., Ford, P. R., McRobert, A. P., & Williams, A. M. (2013). Perceptual-cognitive skills and their interaction as a function of task constraints in soccer. *Journal of Sport & Exercise Psychology, 35,* 144-155.

Roca, A., Ford, P. R., McRobert, A. P., & Williams, A. M. (2011). Identifying the processes underpinning anticipation and decision-making in a dynamic time-constrained task. *Cognitive Processing, 12,* 301-310.

Roca, A., Williams, A. M., & Ford, P. R. (2012). Developmental activities and the acquisition of superior anticipation and decision making in soccer players. *Journal of Sports Sciences, 30,* 1643-1652.

Roca, A., Williams, A. M., & Ford, P. R. (2014). Capturing and testing perceptual-cognitive expertise: A comparison of stationary and movement response methods. *Behavior Research Methods, 46,* 173-177.

Rosalie, S. M., & Müller, S. (2013). Timing of in situ visual information pick-up that differentiates expert and near-expert anticipation in a complex motor skill. *The Quarterly Journal of Experimental Psychology, 66,* 1951-1962.

Rosenthal, D. M. (2000). Consciousness, content, and metacognitive judgments. *Consciousness and Cognition, 9*, 203-214.

Rowe, R., Horswill, M. S., Kronvall-Parkinson, M., Poulter, D. R., & McKenna, F. P. (2009). The effect of disguise on novice and expert tennis players' anticipation ability. *Journal of Applied Sport Psychology, 21*, 178-185.

Runswick, O. R., Roca, A., Williams, A. M., Bezodis, N. E., & North, J. S. (2017). The effects of anxiety and situation-specific context on perceptual-motor skill: A multi-level investigation.

Ryu, D., Abernethy, B., Mann, D. L., Poolton, J. M., & Gorman, A. D. (2013). The role of central and peripheral vision in expert decision making. *Perception, 42,* 591-607.

Saariluoma, P. (1984). *Coding problem spaces in chess: A psychological study*. (Commentationes Scientarium Socialum, Vo. 23). Turku: Societas Scientiarum Fennica.

Salmela, J. H., & Fiorito, P. (1979). Visual cues in ice hockey goaltending. *Canadian Journal of Applied Sport Sciences, 4*, 56-59.

Savelsbergh, G. J. P., van der Kamp, J., Williams, A. M., & Ward, P. (2005). Anticipation and visual search behaviour in expert soccer goalkeepers. *Ergonomics, 48*, 1686-1697.

Savelsbergh, G. J. P., Williams, A. M., van der Kamp, J., & Ward, P. (2002). Visual search, anticipation and expertise in soccer goalkeepers. *Journal of Sports Sciences, 20*, 279-287.

Schläppi-Lienhard, O., & Hossner, E. (2015). Decision making in beach volleyball defense: Crucial factors derived from interviews with top-level experts. *Psychology of Sport and Exercise, 16*, 60-73.

Sebanz, N., & Shiffrar, M. (2009). Detecting deception in a bluffing body: The role of expertise. *Psychonomic Bulletin & Review, 16*, 170-175.

Shim, J., & Carlton, L. G. (1997). Perception of kinematic characteristics in the motion of lifted weight. *Journal of Motor Behavior, 29*, 131-146.

Shim, J., Carlton, L. G., & Kwon, Y. (2006). Perception of kinematic characteristics of tennis strokes for anticipating stroke type and direction. *Research Quarterly for Exercise and Sport, 77*, 326-339.

Simon, H. A., & Chase, W. G. (1973). Skill in chess. *American Scientist, 61*, 394-403.

Singer, R. N. (2000). Performance and human factors: Considerations about cognition and attention for self-paced and externally-paced events. *Ergonomics, 43*, 1661-1680.

Singer, R. N., Cauraugh, J. H., Chen, D., Steinberg, G. M., & Frehlich, S. G. (1996). Visual search, anticipation, and reactive comparisons between highly-skilled and beginning tennis players. *Journal of Applied Sport Psychology, 8*, 9-26.

Singer, R. N., Williams, A. M., Frehlich, S. G., Janelle, C. M., Radlo, S. J., Barba, D. A., & Bouchard, L. J. (1998). New frontiers in visual search: An exploratory study in live tennis situations. *Research Quarterly for Exercise and Sport, 69*, 290-296.

Smeeton, N. J., & Williams, A. M. (2012). The role of movement exaggeration in the anticipation of deceptive soccer penalty kicks. *British Journal of Psychology, 103*, 539-555.

Smeeton, N. J., Williams, A. M., Hodges, N. J., & Ward, P. (2005). The relative effectiveness of various instructional approaches in developing anticipation skill. *Journal of Experimental Psychology: Applied, 11*, 98-110.

Spittle, M., Kremer, P., & Hamilton, J. (2010). The effect of screen size on video-based perceptual decision making tasks in sport. *International Journal of Sport and Exercise Psychology, 8*, 360-372.

Spitz, J., Put, K., Wagemans, J., Williams, A. M., & Helsen, W. F. (2016). Visual search behaviors of association football referees during assessment of foul play situations. *Cognitive Research: Principles and Implications, 1*, 1-12.

Starkes, J. L. (1987). Skill in field hockey: The nature of the cognitive advantage. *Journal of Sport Psychology, 9*, 146-160.

Starkes, J. L., & Deakin, J. (1984). Perception in sport: A cognitive approach to skilled performance. In W. F. Straub & J. M. Williams (Eds.), *Cognitive Sport Psychology* (pp. 115-128). Lansing, NY: Sport Science Associates.

Suss, J., & Ward, P. (2012). Use of an option generation paradigm to investigate situation assessment and response selection in law enforcement. *Human Factors and Ergonomics Society Annual Meeting Proceedings, 56*, 297-301.

Tenenbaum, G., Levy-Kolker, N., Bar-Eli, M., & Weinberg, R. (1994). Information recall of younger and older skilled athletes: The role of display complexity, attentional resources and visual exposure duration. *Journal of Sports Sciences, 12*, 529-534.

Tenenbaum, G., Levy-Kolker, N., Sade, S., Liebermann, D. G., & Lidor, R. (1996). Anticipation and confidence of decisions related to skilled performance. *International Journal of Sport Psychology, 27*, 293-307.

Terman, L. M., & Oden, M. H. (1959). *Genetic studies of genius. Vol. V. The gifted group at mid-life*. Oxford: Stanford University Press.

Thomas, J. R., Nelson, J. K., & Silverman, S. J. (2005). *Research methods in physical activity* (5th ed.). Champaign, IL: Human Kinetics.

Triolet, C., Benguigui, N., Le Runigo, C., & Williams, A. M. (2013). Quantifying the nature of anticipation in professional tennis. *Journal of Sports Sciences, 31*, 820-830.

Underwood, G. (2007). Visual attention and the transition from novice to advanced driver. *Ergonomics, 50*, 1235-1249.

Vaeyens, R., Lenoir, M., Williams, A. M., Mazyn, L., & Philippaerts, R. M. (2007). The effects of task constraints on visual search behavior and decision-making skill in youth soccer players. *Journal of Sport & Exercise Psychology, 29*, 147-169.

van der Kamp, J., Rivas, F., van Doorn, H., & Savelsbergh, G. (2008). Ventral and dorsal system contributions to visual anticipation in fast ball sports. *International Journal of Sport Psychology, 39*, 100.

van Maarseveen, M. J. J., Oudejans, R. R. D., Mann, D. L., & Savelsbergh, G. J. P. (2016). Perceptual-cognitive skill and the in situ performance of soccer players. *The Quarterly Journal of Experimental Psychology*, 1-17.

van Maarseveen, M. J. J., Oudejans, R. R. D., & Savelsbergh, G. J. P. (2015). Pattern recall skills of talented soccer players: Two new methods applied. *Human Movement Science, 41*, 59-75.

Vater, C., Roca, A., & Williams, A. M. (2015). Effects of anxiety on anticipation and visual search in dynamic, time-constrained situations. *Sport, Exercise, and Performance Psychology, 5*, 179.

Verkoeijen, P. P. J. L., Rikers, R. M. J. P., Schmidt, H. G., van de Wiel, M. W. J., & Kooman, J. P. (2004). Case representation by medical experts, intermediates and novices for laboratory data presented with or without a clinical context. *Medical Education, 38*, 617-627.

Ward, P. (2003). *The development of perceptual-cognitive expertise*. Unpublished doctoral thesis. Liverpool John Moores University.

Ward, P., Ericsson, K. A., & Williams, A. M. (2013). Complex perceptual-cognitive expertise in a simulated task environment. *Journal of Cognitive Engineering and Decision Making, 7*, 231-254.

Ward, P., Suss, J., Eccles, D. W., Williams, A. M., & Harris, K. R. (2011). Skill-based differences in option generation in a complex task: A verbal protocol analysis. *Cognitive Processing, 12,* 289-300.

Ward, P., & Williams, A. M. (2003). Perceptual and cognitive skill development in soccer: The multidimensional nature of expert performance. *Journal of Sport and Exercise Psychology, 25*, 93-111.

Ward, P., Williams, A. M., & Bennett, S. J. (2002). Visual search and biological motion perception in tennis. *Research Quarterly for Exercise and Sport, 73*, 107-112.

Watson, J. B. (1924). *Behaviorism*. New York, NY: Norton.

Williams, A. M. (2000). Perceptual skill in soccer: Implications for talent identification and development. *Journal of Sports Sciences, 18,* 737-750.

Williams, A. M. (2009). Perceiving the intentions of others: How do skilled performers make anticipation judgments? In M. Raab, J. G. Johnson, & H. R. Heekeren (Eds.), *Progress in Brain Research: Vol. 174. Mind and Motion: The Bidirectional Link Between Thought and Action* (pp. 73-83). Amsterdam: Elsevier.

Williams, A. M., & Burwitz, L. (1993). Advance cue utilization in soccer. In T. Reilly, J. Clarys, & A. Stibbe (Eds.), *Science and Football II* (pp. 239-244). London: E & FN Spon.

Williams, A. M., & Davids, K. (1995). Declarative knowledge in sport: A by-product of experience or a characteristic of expertise? *Journal of Sport and Exercise Psychology, 17*, 259-275.

Williams, A. M., & Davids, K. (1997). Assessing cue usage in performance contexts: A comparison between eye-movement and concurrent verbal report methods. *Behavior Research Methods, Instruments, & Computers, 29,* 364-375.

Williams, A. M., & Davids, K. (1998). Visual search strategy, selective attention, and expertise in soccer. *Research Quarterly for Exercise and Sport, 69,* 111-128.

Williams, A. M., Davids, K., Burwitz, L., & Williams, J. (1993). Cognitive knowledge and soccer performance. *Perceptual and Motor Skills, 76*, 579-593.

Williams, A. M., Davids, K., & Williams, J. G. (1999). *Visual perception and action in sport*. London: E & FN Spon.

Williams, A. M., & Elliott, D. (1999). Anxiety, expertise, and visual search strategy in karate. *Journal of Sport and Exercise Psychology, 21*, 362-375.

Williams, A. M., & Ericsson, K. A. (2005). Perceptual-cognitive expertise in sport: Some considerations when applying the expert performance approach. *Human Movement Science, 24*, 283-307.

Williams, A. M., Ericsson, K. A., Ward, P., & Eccles, D. W. (2008). Research on expertise in sport: Implications for the military. *Military Psychology, 20,* S123-S145.

Williams, A. M., & Ford, P. (2008). Expertise and expert performance in sport. *International Review of Sport and Exercise Psychology, 1,* 4-18.

Williams, A. M., Ford, P. R., Eccles, D. W., & Ward, P. (2011). Perceptual-cognitive expertise in sport and its acquisition: Implications for applied cognitive psychology. *Applied Cognitive Psychology, 25*, 432-442.

Williams, A. M., Hodges, N. J., North, J. S., & Barton, G. (2006). Perceiving patterns of play in dynamic sport tasks: Investigating the essential information underlying skilled performance. *Perception, 35,* 317-332.

Williams, A. M., Janelle, C. M., & Davids, K. (2004). Constraints on the search for visual information in sport. *International Journal of Sport and Exercise Psychology, 2*, 301-318.

Williams, A. M., North, J. S., & Hope, E. R. (2012). Identifying the mechanisms underpinning recognition of structured sequences of action. *The Quarterly Journal of Experimental Psychology, 65*, 1975-1992.

Williams, A. M., & Reilly, T. (2000). Talent identification and development in soccer. *Journal of Sports Sciences, 18*, 657-667.

Williams, A. M., & Ward, P. (2007). Anticipation and decision making: Exploring new horizons. In G. Tenenbaum & R. Ecklund (Eds.), *Handbook of Sport Psychology* (3rd ed.) (pp. 203-223). Hoboken, NJ: John Wiley & Sons.

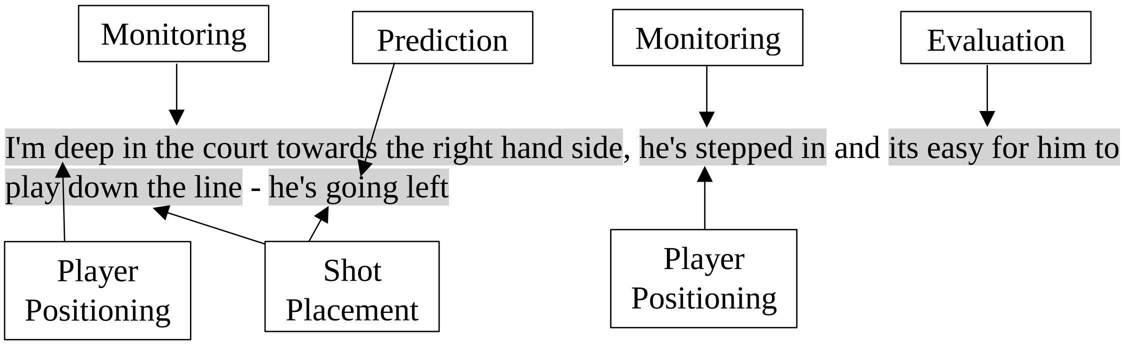
Williams, A. M., Ward, P., Knowles, J. M., & Smeeton, N. J. (2002). Anticipation skill in a real-world task: Measurement, training, and transfer in tennis. *Journal of Experimental Psychology: Applied, 8*, 259-270.

Appendix

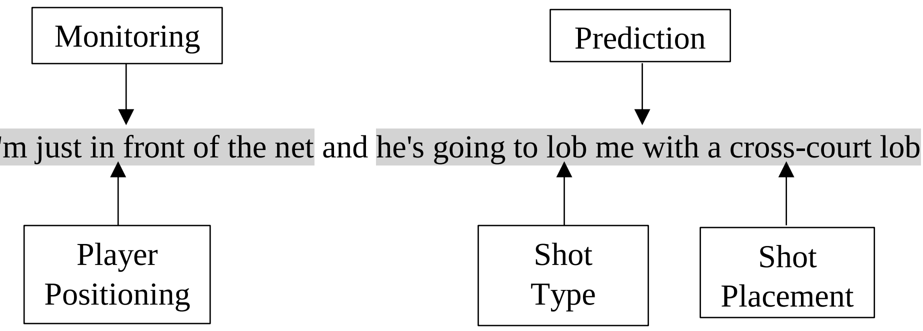
Examples of Verbal Reports

Statement type is indicated above the verbal report, keyword type is indicated below.

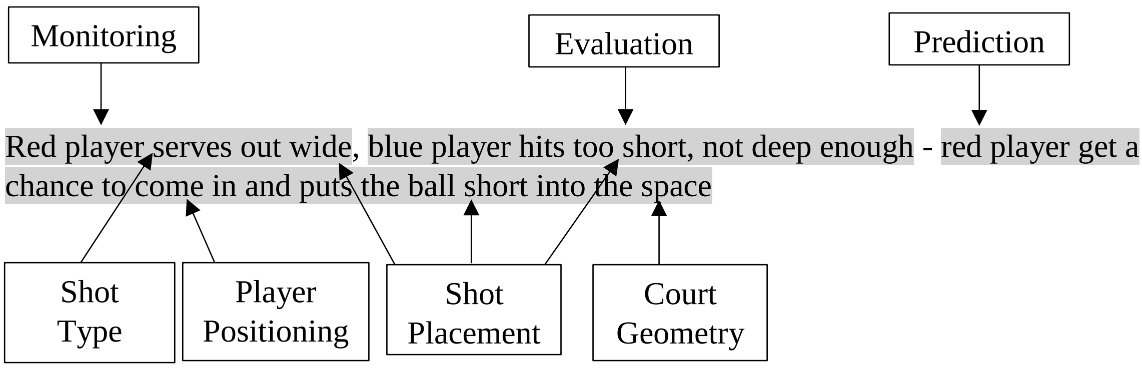
Less-Skilled Participant Example 1



Less-Skilled Participant Example 2



Skilled Participant Example 1



Skilled Participant Example 2