THE INTEGRATION OF EXPLICIT CONTEXTUAL PRIORS AND VISUAL INFORMATION DURING ACTION ANTICIPATION IN SOCCER

A Thesis Submitted for the Degree of Doctor of Philosophy

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Abstract

The overarching aim of this thesis was to gain further insights into expert athletes' integration of explicit contextual priors and visual information during action anticipation. In order to achieve this, four experimental studies were conducted, in which soccer players had to predict the forthcoming actions of oncoming opponents, both with and without explicit priors pertaining to their action tendencies. The first study examined skill-level differences with regard to the impact of explicit contextual priors on task performance and the processing strategies employed. Experts integrated explicit contextual priors to inform their acquisition of visual information more effectively than novices, which resulted in superior task performance. The second study explored the extent to which the comparative reliability of explicit contextual priors and visual information affected experts' anticipatory judgements. The impact of priors decreased as their reliability decreased relative to the opponent's kinematics, and vice versa. The third study investigated the impact of explicit contextual priors on experts' cognitive load and the extent to which their performance was modulated by task load. Online psychophysiological measures, but not retrospective self-reports, revealed that explicit contextual priors evoked increases in cognitive load. Furthermore, increased task load seemed to disrupt the integration of priors and visual information, which negatively affected anticipation performance. The fourth study examined the impact of judgement utility on experts' anticipatory judgements and their integration of contextual priors with visual information. Judgement utility supressed the players' reliance upon contextual priors and pertinent visual information and biased their judgement toward the option of comparatively higher utility. These findings have implications for the development of an overarching theoretical framework of action anticipation in sport, they provide valuable applied insight with regard to the usefulness of explicit contextual priors in performance settings, and highlight important methodological issues concerning the assessment of athletes' information acquisition and integration processes during action anticipation tasks.

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Chapter 1: Introduction

1.1 Context of the Thesis

We are frequently required to make accurate estimates about the state of an uncertain world, with only probabilistic information to hand (Brunswik, 1952). The ability to make predictive judgements about the world around us, often on the basis of ever-changing and partial information, is therefore integral to skilled performance. Successful anticipation of what is likely to happen, before it actually happens, is deemed to be particularly important when performing in dynamic and rapidly evolving environments, such as those encountered in many sports (Williams, Ford, Eccles, & Ward, 2011). In defensive soccer situations, which is the focus of this thesis, fast and accurate anticipation of an oncoming attacker's next move can be crucial in order for the defender to select and execute an appropriate action in time to prevent a goal-scoring opportunity (Williams, 2000).

It is well-established that expert athletes are superior to novice athletes at utilising advance visual information, such as an oncoming opponent's kinematics, in order to inform their anticipatory judgements (Mann, Williams, Ward, & Janelle, 2007). However, in recent years, an increasing body of research has begun to explore the effect of providing a priori information that is relevant to the specific performance context – so-called *contextual priors* – during action anticipation in sport (Cañal-Bruland & Mann, 2015). Due to advances in technology that enable sophisticated analyses of opponents, an increasingly prevalent component of elite sport preparation is to provide athletes with contextual priors pertaining to the behaviours of forthcoming opponents (Memmert, Lemmink, & Sampaio, 2017). Despite these developments, researchers and sport practitioners still have little understanding of the impact of such information on anticipation performance, and the associated perceptual and cognitive processes, under various performance conditions.

In the quest for an overarching framework to explain anticipation, it has been suggested that athletes may employ Bayesian reliability-based strategies in order to integrate contextual priors with evolving visual information during anticipation (Loffing & Cañal-Bruland, 2017). That is, their dependency on contextual priors and visual information is modulated by the reliability of the information at hand, with greater weight assigned to information that is perceived as more reliable. Furthermore, Bayesian theory postulates that people strive not only to maximise the likelihood that their judgements will be accurate, but also to maximise the utility of the consequences of their judgement (Vilares & Körding, 2011). However, the applicability of these assumptions to action anticipation in sport is yet to be explored.

1.2 Structure of the Thesis

This introduction is followed by a critical review of the literature that is pertinent to the present research programme (Chapter 2). Chapters 3 to 6 detail the four experimental studies that comprise the programme of research. Although interrelated, each chapter addresses different research questions, and therefore has its own introduction, including a review of the literature relevant to the specific study. Due to the core themes that run through the thesis, there is inevitably some repetition of material, but this is kept to a minimum. Chapter 7 provides a general discussion that summarises the key findings from the four studies; potential limitations and future research directions are discussed, along with the theoretical, methodological, and practical implications emanating from this work.

Chapter 2: Literature Review

The aim of this literature review is to provide the reader with an overview of key terminology, theory, and empirical research that underpin the experimental studies of this thesis. In the first section, I provide a brief introduction to the study of expertise in sport. In the second section, I detail research that has sought to explain the perceptual and cognitive processes that underpin skilled action anticipation in sport, with a specific focus on athletes' use of visual information and contextual priors. In the third section, I provide an overview of Bayesian theory with the intention of demonstrating that this framework might be suitable for the examination of action anticipation in sport. In section four, I discuss the potential increases in processing demands of integrating contextual priors with visual information, and how the impact of contextual priors may be modulated by the cognitive demands of the task and judgement utility. In the fifth and final section, I provide a synopsis of the topics reviewed and a rationale for this thesis, including its main objectives and expected implications.

2.1 Sport Expertise

A historical view of expertise is that skilled performers have been born with 'natural' abilities, superior to those of less-skilled performers (Galton, 1869). For example, an early supposition of scientists seeking to explain expert characteristics in sport was that experts were endowed with superior visual attributes, compared to novice athletes (e.g., Beals, Mayyasi, Templeton, & Johnston, 1971; Fullerton, 1921; Olsen, 1956). More recently, however, there has been an increasing consensus that skilled performance in sports is not determined by basic visual functions, such as visual acuity and depth perception (e.g., Abernethy, Neal, & Koning, 1994; Helsen & Starkes, 1999; Ward & Williams, 2003). For example, Mann and colleagues (Mann, Abernethy, & Farrow, 2010a; Mann, Abernethy, & Farrow, 2010b; Mann, Ho, De Souza, Watson, & Taylor, 2007) used a blurring technique to degrade the visual clarity of expert cricket batters as they performed an interceptive task. The authors demonstrated that, in order to negatively affect performance, visual clarity had to be significantly reduced – in some cases to a level comparable to legal blindness. Although optometric and physical properties of the visual system may set some very basic limits on performance, the manner in which athletes *use* their visual system to acquire pertinent visual information is deemed to be a stronger predictor of expertise (Ward & Williams, 2003).

With regard to basic cognitive functions, research into skill-level differences has yielded mixed results (Voss, Kramer, Basak, Prakash, & Roberts, 2010). For example, Vestberg, Gustafson, Maurex, Ingvar, and Petrovic (2012) demonstrated that elite soccer players outperformed sub-elite players on generic cognitive tests of executive functions. However, in a study by Spitz, Put, Wagemans, Williams, and Helsen (2018), an extensive battery of several domain-generic tests including attentional inhibition, general processing speed, and attentional switching, did not reveal any differences between elite and sub-elite soccer referees. Importantly, the use of generic tests in order to assess perceptual and cognitive expertise in sport has been criticised for not capturing the complexities of environments that generate superior expert performance (Ericsson, 2003). Hence, the degree to which the test task represents the athletes' natural performance conditions is a key component of the expert performance approach forwarded by Ericsson and Smith (1991).

2.1.1 The expert performance approach. The expert performance approach is a three-stage framework that allows researchers to systematically investigate expert performance. In the first stage, researchers aim to develop a test task that can accurately capture experts' superior performance in the domain of interest. Researchers should seek to recreate the same task constraints as those encountered under natural performance conditions, but at the same time strive to make the test task as repeatable and standardised as possible (Williams & Ericsson, 2005). There is a fundamental trade-off between high experimental control in laboratory-based designs and real-world representativeness in field-based designs, so researchers must carefully consider the applicability of each approach with regard to their specific research questions (Kredel, Vater, Klostermann, & Hossner, 2017). When using laboratory-based video tasks, which afford greater experimental control, researchers can employ life-size point-of-view projected images, with response modalities that more accurately reflect movements performed in the real world, in order to increase the representativeness of the task (e.g., McRobert, Ward, Eccles, & Williams, 2011; Roca, Ford, McRobert, & Williams, 2013; Runswick et al., 2018a).

In the second stage of the expert performance approach, researchers seek to identify the mechanisms that underpin expert performance. This can be achieved via acquisition of data from experimental manipulations (e.g., instructional approaches, secondary task demands, progressive temporal occlusion of test stimuli), online process measures (e.g., eye tracking, electroencephalography [EEG]), and/or retrospective self-reports (e.g., rating scales, verbal report protocols; Williams & Ericsson, 2005). As with performance measures, a representative task design is deemed to be crucial in order to identify underlying perceptual and cognitive strategies comparable to those employed in real-world settings (Dicks, Button, & Davids, 2010).

In the third and final stage of the framework, researchers attempt to explain how requisite skills are developed, which can be achieved via practice history profiling or training interventions (Williams & Ericsson, 2005). The focus of the present research programme is on the first and second stages of the expert performance approach; namely, the perceptual and cognitive strategies that are employed by expert soccer players as they perform a representative action anticipation task. In the next section, I provide a critical review of existing sport literature that is pertinent to the experimental chapters of this thesis.

2.2 Expert Action Anticipation in Sport

Action anticipation has been described as the ability to recognise the outcome of others' actions prior to and during the execution of those actions (Williams & Ford, 2013). Across a wide range of sports, expert athletes have consistently demonstrated the ability to anticipate their opponents' action faster and more accurately than their less skilled counterparts (Mann et al., 2007). Indeed, in soccer, this particular attribute is deemed to account for a greater proportion of the variance in the performances of expert and novice players than physical or physiological ones (Williams & Reilly, 2000).

2.2.1 Visual information. It is well established that athletes are able to pick up and use advance visual information in order to predict opponents' future actions. In a meta-analysis of 42 studies, Mann and colleagues (2007) reported that expert athletes extract advance visual information more efficiently than novices, which, in turn, enables them to anticipate faster and more accurately than their less skilled counterparts. It is deemed that the skilled performers' advantage is due to extensive accumulation of domain-specific experience – and the result is greater attunement to task-relevant cues (Williams & Ford, 2008). During action anticipation in sport, visual information typically refers to the opponent's kinematics, which can be valid or invalid (e.g., deceptive movements; Jackson, Warren, & Abernethy, 2006) with regard to the to-be-anticipated action. However, in the current thesis, the term *visual information* refers to any kind of valid information that is visually available during task performance.

In recent years, mobile eye-tracking devices have increasingly been used to characterise the visual search strategies that athletes employ in order to acquire visual information during performance of anticipation tasks. These devices determine the coordinates of the wearer's current point-of-gaze, relative to a live video stream of their visual environment; these data can be recorded and stored for subsequent analysis. Amongst variables such as fixation rate, saccade durations and amplitudes, the distribution of fixations and dwell time on areas of interest have been analysed, in attempts to better understand the processes by which athletes extract visual information during task performance (Kredel et al., 2017; Vansteenkiste, Cardon, Philippaerts, & Lenoir, 2015).

Roca, Ford, McRobert, and Williams (2011) employed this technique on a video-based task comprising simulated 11-versus-11 defensive soccer scenarios, in which expert and novice players had to predict opponents' next moves. The authors captured the players' anticipation performance as well as their allocation of overt visual attention during the task. In addition to being more accurate, expert players allocated their attention away from the player in possession and toward the players off the ball – who were deemed to be informative with regard to the task solution – to a greater extent than novices. Eye-tracking methods were also employed in a study by Savelsbergh, Williams, van der Kamp, and Ward (2002), in which expert and novice soccer goalkeepers had to anticipate the direction of penalty kicks. Expert goalkeepers were more accurate and attended to task-relevant visual information, such as the non-kicking leg of the penalty taker (see Franks & Hanvey, 1997), to a greater extent than novice goalkeepers. Furthermore, by analysing the eye movement data for different stages of the penalty kick, it was revealed that expert goalkeepers' processing priorities changed over time. For example, goalkeepers' attention toward upper-body cues (i.e., head, shoulders, and trunk) decreased as the penalty taker approached the ball, and more attention was devoted toward the legs and the ball, as these latter sources of information became increasingly more reliable with regard to the shot direction of the kick.

It is worth noting that eye-tracking data are merely an index of overt attention, without assessing covert allocation of attention. Hence, point-of-gaze does not entirely reflect the athlete's allocation of attention, if they are covertly attending to cues in the visual periphery (Mann & Savelsbergh, 2015). Although this may be less of a concern than previously thought (Ryu, Abernethy, Mann, & Poolton, 2015), it is deemed that expert athletes use their peripheral vison more effectively than novices to inform anticipation (Schorer, Rienhoff, Fischer, & Baker, 2013) and decision making (Ryu, Abernethy, Mann, Poolton, & Gorman, 2013). Hence, a complementary process tracing measure, which provides additional insight into athletes' processing priorities during action anticipation, is the collection of immediate retrospective verbal reports of the thought processes they engaged in during task performance (Ericsson & Simon, 1980). In an immediate retrospective verbal report protocol, the athlete is required to recollect their thought processes for the preceding trial. They should recall their thoughts as they were naturally experienced during the trial, rather than elaborating or providing commentary on them. This procedure is deemed to enable access to information held in short-term memory during task performance (for a review, see Eccles, 2012). This information can then be coded into predefined information categories, in order to compare processing priorities across athletes or experimental conditions (e.g., Murphy et al., 2016;

Runswick, et al., 2018a). This technique may be particularly advantageous when examining the processes by which athletes integrate visual and non-visual information, such as contextual priors, during performance; thus, research that has utilised this technique will be further described in the next section.

Another technique that has been used to assess the impact of visual information during action anticipation is the progressive temporal occlusion paradigm. Typically, this technique requires the participant to respond to video stimuli which are occluded at various time points relative to the unfolding of the to-be-anticipated action (however, for applications of this approach in more naturalistic settings, see e.g., Farrow, Abernethy, & Jackson, 2005; Müller et al., 2009; Müller & Abernethy, 2006). By comparing athletes' response accuracy across various occlusion conditions, researchers have shown that access to later – and therefore more reliable – kinematic information enhances athletes' performance when they try to predict an oncoming opponent's next move. Furthermore, it has been shown that skilled athletes are better at extracting this information earlier than their less skilled counterparts (e.g., Farrow et al., 2005; Loffing & Hagemann, 2014; Wright, Bishop, Jackson, & Abernethy, 2013).

The temporal occlusion paradigm was employed in a study by Farrow and colleagues (2005), in which expert and novice players were required to predict the direction of forthcoming tennis serves. It was demonstrated that both expert and novice players were more accurate when the video clips were occluded closer to racket-ball contact (i.e., when kinematic cues were highly reliable), compared to earlier occlusion points (i.e., when kinematic cues were less reliable). Furthermore, it was observed that expert players detected pertinent kinematic information earlier than novices. Additionally, the authors compared full-length videos whose duration varied across occlusion conditions, to moving windows that captured different phases of the service action, but where the durations of the visual display were constant across occlusion conditions. The findings from this comparison suggested that the reliability of visual information – expressed by its impact on response accuracy – was not modulated by the total amount of kinematic information available prior to occlusion, but rather by the relevance of the kinematics with regard to serve direction.

2.2.1.1 A framework for visual information integration. In an attempt to illustrate athletes' temporal integration of visual information, Müller and Abernethy (2012) created a model that sought to predict the anticipatory processes of expert and novice striking sport athletes (see also Morris-Binelli & Müller, 2017). The model proposes that, when tasked with anticipating and intercepting opponents' actions (e.g., a tennis shot), athletes adapt their processing priorities over time according to the level of specificity of the informational variables at hand: as unfolding visual information becomes more specific, and therefore more reliable, with regard to the forthcoming action, athletes refine their anticipatory judgements correspondingly. Importantly, the model predicts that, since expert athletes are more attuned to task-relevant information, they are able to infer the reliability of evolving visual information more quickly and accurately than novices, resulting in superior performance. This model implies that striking sport athletes employ reliability-based strategies to integrate various sources of visual information during action anticipation. Namely, the athletes seem to enhance their anticipation performance as the reliability of available visual information increases. The reliability assigned to visual cues seems to be modulated not only by their relevance with regard to the impending action, but also by the athlete's ability to utilise information as it becomes available. Accordingly, expert athletes seem to be better at adjusting their information processing priorities as the relevance of evolving visual information changes over time and, as such, they become better anticipators than their less skilled peers.

Müller and Abernethy (2012) also emphasised that a priori probabilistic information, in the form of expectations and beliefs, is likely to influence athletes' anticipatory processes, but stressed that our understanding of how such information is used by athletes is limited. Furthermore, as the environmental constraints differ across sport types, the perceptual and cognitive processes characterising expertise in striking sports may be different from those in more dynamic and information-rich environments, such as in soccer (see Mann et al., 2007). Thus, there is a need to broaden the focus when examining the nature of expert anticipation in sport, including the impact of contextual priors.

2.2.2 Contextual priors. Research has demonstrated that expert athletes are still able to anticipate more accurately than novice athletes, even in the absence of reliable visual information (Bruce Abernethy, Gill, Parks, & Packer, 2001; Triolet, Benguigui, Le Runigo, & Williams, 2013). Under such conditions, it is deemed that athletes may integrate contextual priors in order to inform their anticipatory judgements. In recent years, an increasing body of research has tried to elucidate the extent to which contextual priors, such as behaviours associated with certain game states (Farrow & Reid, 2012; Runswick et al., 2018a), familiarity with specific opponents' action tendencies (Gray, 2015; Loffing, Stern, & Hagemann, 2015; Mann, Schaefers, & Cañal-Bruland, 2014; McRobert et al., 2011; Runswick et al., 2018a), or explicit knowledge of a particular opponent's action tendencies

(Broadbent, Gredin, Rye, Williams, & Bishop, 2018; Gray, 2015; Gray & Cañal-Bruland, 2018; Navia, Van der Kamp, & Ruiz, 2013), affect action anticipation.

Loffing and colleagues (2015) demonstrated that exposure to a volleyball opponent's previous action patterns biased expert players' anticipatory judgements of the type of shot (lob or smash) the opponent would perform next. Specifically, the players tended to opt for the most likely action, given the preceding action pattern. Consequently, reliance upon the opponent's prior action tendencies resulted in faster and more accurate judgements when the to-be-anticipated action was congruent with the preceding pattern, compared to when it was not. Furthermore, it was revealed that expert players were biased by the opponent's preceding action patterns to a greater extent than novices. In a similar vein, Mann and colleagues (2014) revealed penalty takers' action tendencies to expert handball goalkeepers over a training period (75% of all penalty throws were directed toward one particular corner of the goal). When they subsequently attempted to predict the direction of penalty takers' throws, the goalkeepers biased their judgements according to those action tendencies.

In these two studies, it was assumed that the athletes accrued information about the opponents' action tendencies by picking up patterns or trends from the opponents' preceding actions – that is, they did not receive explicit instructions or guidance pertaining to this information. However, using a simulated protocol, Gray (2015) *explicitly* primed expert baseball batters with information about a pitcher's action tendencies. These explicit contextual priors were shown to enhance batting performance immediately after they were provided, as well as after a training period during which the batters faced the pitcher *and* received explicit information about his action tendencies. However, when the batters faced a new pitcher, with different action tendencies, the explicit provision of contextual priors adversely affected their performance. Furthermore, the batters performed better on high-probability pitches (the chance for pitch location and pitch type to occur were both ≥ 70%, given the pitcher's action tendencies) than they did on low-probability-pitches. Interestingly, this effect was also found for batters who did not receive any explicit information about the pitcher's action tendencies – even before they took part in any training (repetitive exposure to the batter's action tendencies). This suggests that the batters held prior expectations with regard to pitch type and pitch location which reconciled, at least to some extent, with the pitcher's actual action tendencies.

The explicit provision of contextual priors was also employed in a study by Broadbent and colleagues (2018), in which expert soccer players had to predict the direction of an oncoming opponent's next move. The players performed the task with and without explicit contextual priors pertaining to the opponent's action tendencies (leftward outcomes = 65% chance, rightward outcomes = 35% chance). Response accuracy increased when the opponent performed the most likely action, given his action tendencies (i.e., leftward outcomes). A trend toward impaired response accuracy was revealed when the opponent performed an action toward the right. In keeping with previous work (Gray, 2015; Loffing et al., 2015; Mann et al., 2014), these findings suggest that the performance effect of contextual priors is contingent on their congruency with evolving visual information. Broadbent and colleagues (2018) proposed that, when the opponent performed the least likely action given his action tendencies, the players used conflicting kinematic information from the oncoming opponent to suppress the biasing effects of the contextual priors. However, none of the aforementioned studies provided insight into the interaction between contextual priors and evolving visual information during task performance.

2.2.3 Integrating contextual priors with visual information. Runswick and colleagues (2018a) sought to examine the processing priorities employed by expert and novice cricket batters as they predicted the location of a bowler's forthcoming deliveries – with and without contextual priors. The authors collected retrospective verbal reports of the batters' thoughts immediately after task performance. It was demonstrated that when facing six consecutive deliveries from the same bowler, and after receipt of prior information pertaining to the game score and field setting, both expert and novice batters' response accuracy improved, compared to when facing six successive deliveries from six different bowlers in the absence of prior information about the game situation. Verbal report data revealed that expert batters, more so than novices, changed their processing priorities when contextual priors were provided. Specifically, in this condition, the expert batters verbalised a higher number of statements relating to prior information about the bowlers' action tendencies, the state of the game, and the field setting, whereas fewer statements referred to the bowlers' kinematic information.

Using the same anticipation task, Runswick and colleagues (2018b) combined a temporal occlusion paradigm with retrospective information score rating, in order to explore the temporal interaction of contextual priors and evolving visual information. The rating revealed that the batters' reliance upon contextual priors pertaining to the bowler's action tendencies, game state, and field setting was dominant during the early stages of the bowler's run-up, whereas visual information relating to the bowler's kinematics and ball flight became the dominant sources of information nearer to the point of ball release. It was shown that reliance on both contextual priors (during the early stages of run-up) and pertinent visual information (around ball release) was more pronounced in expert, than in novice, batters.

Navia and colleagues (2013) analysed the distribution of expert soccer goalkeepers' visual dwell time as they predicted the direction of, and tried to save, penalty kicks in naturalistic settings. The goalkeepers performed the task under two conditions in which the penalties were equally distributed toward each side of the goal (left side = 50%, right side = 50%) and two conditions with skewed distributions (left side = 80%, right side = 20%; left side = 20%, right side = 80%). In one of the equal distribution conditions and in both skewed distribution conditions, the goalkeepers received explicit contextual priors containing information about these probabilities. It was shown that the goalkeepers initiated their movements earlier when they received this information, compared to when they did not. In the skewed-distribution conditions, they biased their anticipatory judgements toward the most likely side, given the penalty taker's action tendencies. This biasing effect resulted in greater anticipation accuracy in the two skewed-distribution conditions, compared to the two conditions where the penalties were equally distribution toward each side of the goal. Gaze data from four of the goalkeepers were analysed and showed that explicit contextual priors did not seem to affect the goalkeepers' allocation of overt visual attention. However, it was observed that goalkeepers who spent less time attending to opponents' kinematics were more affected by the explicit provision of contextual priors.

Gray and Cañal-Bruland (2018) employed the same task as Gray (2015) to examine the effect of priors on baseball batters' anticipation performance. However, in addition to priming the batters with explicit information about the pitcher's action tendencies, they also altered the reliability of these action tendencies (e.g., the chance that the pitcher would throw a fastball was either 50%, 65%, or 80%) and the reliability of pertinent visual information (the ball was occluded 50, 100, and 150 ms after the pitcher had released the ball). It was shown that the batters performed best in the condition with high-reliability contextual priors (e.g., fastball = 80% chance) and high-reliability visual information (i.e., ball occlusion after 150 ms). Furthermore, the impact of contextual priors on batting performance was shown to increase as the reliability of visual information decreased. However, the authors did not control for the effect of congruency between contextual priors and evolving visual information. Thus, it remains unclear whether the superior performance revealed when the pitcher exhibited strong, rather than subtle, action tendencies was driven by the extent to which the batters anticipated the 'most likely pitch', or merely by the fact that doing so was more beneficial in the former condition.

The research reviewed in this section highlights that, in addition to visual information, athletes seem to use contextual priors to inform their anticipatory judgements. Researchers have employed various experimental designs in order to study the impact of opponents' action tendencies – one type of contextual priors – during action anticipation. These studies indicate that awareness of such priors, whether induced by explicit guidance (Broadbent et al., 2018; Gray, 2015; Navia et al., 2013) or acquired in a more implicit manner (Loffing et al., 2015; Mann et al., 2014), biases athletes' anticipatory judgements toward the most likely outcome, given the opponent's action tendencies. The awareness of contextual priors seems to reduce athletes' reliance on evolving kinematic information (Runswick et al., 2018a) and, conversely, higher reliance on evolving kinematic information appears to reduce dependency on contextual priors (Navia et al., 2013). Furthermore, the effects of contextual priors, both on anticipatory judgements (Loffing et al., 2015) and processing priorities during task performance (Runswick et al., 2018a), seems to be more pronounced in expert than novice athletes. It appears that athletes' dependency upon contextual priors seems to be contingent on not only the reliability associated with the priors themselves (Gray & Cañal-Bruland, 2018), but also the reliability of evolving visual information (Gray & Cañal-Bruland, 2018; Runswick et al., 2018b).

In the existing literature, contextual priors have been informative with regard to the opponents' forthcoming actions, even in the absence of any visual information. That is, the athletes could use the prior information about the opponent's action tendencies to inform their predictions, without incorporating visual information unfolding over the course of a trial. In complex and highly dynamic performance environments, such as in soccer, the interdependency between contextual priors and visual information may be an important component if we are seeking to elucidate how different information sources are combined during anticipation task performance. Furthermore, the extent to which the effect of congruency between contextual priors and evolving visual information is modulated by the reliability of the different sources of information is yet to be explored. Further insight may be important in order to accurately forecast the utility of contextual priors in dynamic performance environments and/or with athletes of various skill levels.

While a framework has been outlined for the use of visual information in action anticipation (Muller & Abernethy, 2012), no such framework has been proposed for the integration of visual information and contextual priors. This was emphasised by Cañal-Bruland and Mann (2015) who stated that it was time to broaden the scope of research on anticipatory behaviour, such that a solid understanding of contextual priors will lead to the development of an overarching theoretical framework that can predict and explain anticipatory behaviour. Loffing and Cañal-Bruland (2017) followed this call by suggesting that Bayesian theory may provide a suitable framework. However, the predictions of this theory have yet to be explored in dynamic and complex sporting scenarios. Therefore, while the focus of this thesis is to examine the integration of contextual priors and visual information in action anticipation, the present line of investigation will be grounded in Bayesian theory. In the following section I provide a brief theoretical backdrop, including research from non-sport domains, on the key components of Bayesian frameworks.

2.3 Bayesian Theory as a Framework for Action Anticipation

At any given time, the world only provides use with partial and noisy cues regarding its actual state (Brunswik, 1952). A fundamental question for human perception and cognition is therefore, “how do people make inductive judgements that inform their subsequent behaviours from such incomplete information?” Scientists have tried to answer this question by suggesting that people use Bayesian reliability-based strategies to combine available pieces of ambiguous information, in order to reduce the uncertainty of their judgements as much as possible. Bayesian models for probabilistic inference assume that people base their judgements on probabilistic *if-then* relationships between known informational variables and unknown to-be-anticipated variables. That is, *if* ‘X’ (a known informational variable) occurs, *then* there is a certain probability that ‘Y’ (an unknown to-be-anticipated variable) will occur. This process suggests that, if one informational variable is associated with greater reliability (i.e., lower uncertainty) than another, then the individual’s joint estimate should be biased toward the ‘more reliable’ informational variable (Knill & Pouget, 2004).

2.3.1 Combining environmental cues. According to Bayesian theory, each informational variable in our environment has an associated probability distribution that characterises the extent to which it predicts the occurrence of a to-be-anticipated variable. These probability distributions may arise from multiple sources and sensory modalities. In such instances, the observer combines informational variables on the basis of their comparative reliability, resulting in a joint probability distribution which ultimately forms the basis for their judgement (Vilares & Körding, 2011). For example, consider a doctor who is tasked with diagnosing a patient’s condition (the to-be-anticipated variable; e.g., heart attack, viral illness) on the basis of specific symptoms they present (the informational variables; e.g., arrhythmia, pain/discomfort). Each symptom has associated probability distributions, for a range of potential underlying conditions. When taking these symptoms into account, the doctor may consider objectively measurable symptoms (e.g., arrhythmia) to be more reliable than the patient's self-reported symptoms (e.g., pain). While both symptoms are taken into account when making her judgement, the perceived lower reliability of the latter would be reflected in the joint probability distribution and, as such, in the doctor's estimate of the patient's clinical state (see Figure 2.1).

Figure 2.1. Doctor Using Reliability-Based Strategies to Combine Environmental Cues. The doctor assesses the likelihood that a patient is suffering from Disease A or Disease B by weighing objectively measurable symptoms (a) against self-reported symptoms (b). The doctor assigns higher reliability to the former symptoms which is reflected in her joint estimate (c) of the patient's clinical state.

This weighted reliance upon environmental sources of information has been demonstrated in the combination of visual and auditory cues in order to localise events in space (Alais & Burr, 2004; Battaglia, Jacobs, & Aslin, 2003), or visual and haptic cues in order to estimate the size of objects (Ernst & Banks, 2002). People also combine information sources via the same modality (e.g., visual information) in a reliability-based manner. For example, when estimating object shapes (Jacobs & Fine, 1999) or surface slants (Hillis, Watt, Landy, & Banks, 2004; Knill & Saunders, 2003), people integrate texture and motion (Jacobs & Fine, 1999) or texture and binocular disparity (Hillis et al., 2004; Knill & Saunders, 2003), and their ultimate estimates are determined by the reliability of these sources. While it is likely that information from other sensory modalities contributes to athletes' anticipatory judgements (e.g., sound; Cañal-Bruland, Müller, Lach, & Spence, 2018), the current thesis focuses on athletes' use of visual environmental information during action anticipation.

2.3.2 Integrating priors with environmental cues. People do not typically develop their inductive judgements about the world on the basis of available sensory information alone; their prior knowledge and beliefs also impact their judgements. In the case of the doctor making a diagnosis described earlier (Figure 2.1), she may study her patient's medical records before meeting them. The reliability of this prior information would be weighed against the reliability of the presenting symptoms in order to optimise diagnosis accuracy (see Figure 2.2). In Bayesian terms, these priors constitute the probability distribution with regard to the state of the to-be-anticipated variable, prior to the point at which the reliability of current sensory information is taken into account (Vilares & Körding, 2011). These priors are a summary of the task-relevant information that an individual has gathered in the past (Berniker, Voss, & Körding, 2010) and, as such, they contribute to expertise in a given domain. However, task-relevant prior information can also be introduced into experimental designs (Seriès & Seitz, 2013). For example, using simple arm-reaching (Brouwer & Knill, 2009), pointing (Tassinari, Hudson, & Landy, 2006), and event-timing (Miyazaki, Nozaki, & Nakajima, 2005), tasks, researchers have demonstrated that people seem to integrate priors and evolving visual information in a manner described by Bayesian models for probabilistic inference. That is, the reliability on priors and visual information is contingent upon the comparative reliability of the information at hand: dependency on priors increases as the reliability of visual information sources decreases, and vice versa.

Figure 2.2. Doctor Integrating Priors with Environmental Cues. The doctor integrates the patient's medical records (d) with measurable symptoms (a) and self-reported symptoms (b) which modulates the doctor's joint estimate (c) of the likelihoods for Diseases A and B.

In this thesis, priors are referred to as 'contextual priors', which is information that is relevant to the specific performance context and is acquired prior to task performance. In keeping with research using simple and generic sensorimotor tasks (e.g., Brouwer & Knill, 2009; Miyazaki et al., 2005; Tassinari et al., 2006), it has been demonstrated that, in applied settings, people integrate contextual priors and visual information in a reliability-based manner. For example, in forensics, Dror, Péron, Hind, and Charlton (2005) reported that, when people were primed with additional contextual information (e.g., background stories and photos from the crime scene), they were more likely to make 'match' judgements between fingerprints. However, the likelihood of doing so was only increased for ambiguous (i.e., low reliability), and not for clear (i.e., high reliability), fingerprints. Furthermore, it has been suggested that the addition of contextual priors biases the individual's allocation of attention by inducing a top-down, context-driven, selection of visual information (Torralba, 2003). Indeed, this has been demonstrated in law enforcement, where contextual priors biased not only police officers' responses on a judgement task, but also their allocation of visual attention toward context-relevant visual information (Eberhardt, Goff, Purdie, & Davies, 2004).

The integration of contextual priors and visual information may be moderated by other factors, in addition to informational reliability. In the next section, I discuss the potential cognitive load associated with this integration process and how the impact of contextual priors may be modulated by task load and judgement utility.

2.4 Factors Moderating Action Anticipation

2.4.1 Task load. It is believed that the inference and application of *if-then* rules involves semantic memory retrieval processes (De Neys, Schaeken, & D'Ydewalle, 2002) and that increased integration of a priori probabilistic rules may lead to increases in cognitive load (Waldmann & Hagmayer, 2001). For example, during learning of a videogame task requiring fine motor control, Green and Flowers (2003) showed that the explicit provision of prior rules pertaining to the relationship between task features (i.e., *if* 'X' occurs, *then* there is a specific probability that 'Y' will occur) hampered performance during the early stages of learning, compared to when these rules were not explicitly provided. Based on this finding, the authors proposed that the effort expended in trying to remember and apply prior probabilistic rules may detract from an individual's cognitive resources and result in inferior performance, relative to when such rules are not explicitly provided. The assumption that explicit priors may elicit increases in cognitive load has also been proposed in the domains of educational psychology (Reber, 1989), motor learning (Masters, 1992) and sport anticipation (Jackson & Farrow, 2005).

As noted in the previous section, the integration of contextual priors may affect the processing strategies that people employ in order to acquire visual information – notably, the use of top-down, versus bottom-up, attentional processes. Top-down processing refers to strategic allocation of attention and acquisition of information that is driven by the individual's prior knowledge and beliefs. Bottom-up processing, on the other hand, refers to automatic, externally-driven, capture of attention and information acquisition, without top-down mediation (Corbetta & Shulman, 2002). Top-down allocation of visual attention is mediated by the central executive and is therefore deemed to impose greater processing demands than bottom-up, or stimulus-driven, attentional processes (Kaplan & Berman, 2010). Thus, it can be assumed that the integration of contextual priors with evolving visual information during action anticipation may increase cognitive load (i.e., the load imposed on working memory by cognitive processes; Antonenko, Paas, Grabner, & van Gog, 2010). Consequently, it is reasonable to believe that contextual priors would be less effective, both with regard to anticipation performance and the processing strategies employed, under conditions in which the task load (i.e., the complexity of elements inherent in the task; Sweller, 2010) exceeds the limited resources of working memory (see Paas, Tuovinen, Tabbers, & Van Gerven, 2003).

Runswick and colleagues (2018a) sought to test these assumptions by collecting retrospective verbal reports of the cognitive load that expert and novice cricket batters perceived they had invested in the anticipation task. They used The Rating Scale for Mental Effort (RSME; Zijlstra, 1993), a numerical scale that ranges from 0 to 150 and contains nine descriptors; higher ratings indicate higher levels of perceived cognitive load (e.g., 2 = absolutely no effort; 58 = rather much effort; 113 = extreme effort). In contrast to the authors' predictions, contextual priors pertaining to the cricket bowler's action tendencies, game state, and field setting did not alter the batters' perceived cognitive load. These findings align with those reported in studies by Broadbent and colleagues (2018) and Runswick, Roca, Williams, Bezodis, and North (2017) in which RSME was used to assess the processing demands of using contextual priors during a soccer anticipation task and a cricket batting task, respectively. Furthermore, Runswick and colleagues (2018a) implemented a backward-counting task in their design, in order to test the impact of contextual priors under conditions of increased task load. In contrast to predictions, the beneficial effect of priors was greatest under conditions of high task load, for both expert and novice groups. Retrospective verbal reports of thoughts revealed that increased task load affected the batters merely at a behavioural level, without changing their processing priorities of contextual priors and visual information during task performance.

These findings contradict the assumptions that contextual priors would elicit increased cognitive load, and that their impact on performance and processing strategies would decline under more cognitively demanding performance conditions. However, a reason to that these effects were not found may have been due to the fact that the batters were able to inform their judgements from the priors alone, without having to integrate them with evolving visual information. It is possible that this lack of interdependency between contextual priors and evolving visual information reduced the cognitive resources required to use the contextual priors effectively. Another potential explanation could be that the self-report data reflected perceptions of task difficulty, rather than perceived levels of cognitive load. The two concepts are closely related, but task difficulty is determined by the quality and/or volume of information available to solve the task, rather than the individual's cognitive resources. As such, the task can be perceived as less difficult (e.g., in the presence of additional task-relevant information), but at the same time be more cognitively demanding (e.g., increased working memory usage, in order to process additional information), and vice versa (see Westbrook & Braver, 2015). Furthermore, previous research suggests that athletes' reliance upon contextual priors may vary across different stages of task performance (Gray & Cañal-

Bruland, 2018; Runswick et al., 2018b) and subjective retrospective reports may not provide an accurate insight into the temporal fluctuations in cognitive load that may occur over the course of a trial.

Compared to retrospective self-reports, objective online psychophysiological measures, such as EEG, may afford more valid measures of cognitive load during task performance (Antonenko et al., 2010). Specifically, spectral power fluctuations within the theta (θ) and alpha (α) frequencies over frontal and parietal regions, respectively, are deemed to reflect changes in the demands induced by vital cognitive functions, such as central executive attentional control, stimulus inference, and semantic and episodic information processing (see Hsieh & Ranganath, 2014; Klimesch, 1999; Sauseng, Griesmayr, Freunberger, & Klimesch, 2010). EEG has been extensively used as an index of cognitive load outside the sporting domain (e.g., Fuentes et al., 2018; Holm, Lukander, Korpela, Sallinen, & Müller, 2009; Jaquess et al., 2017) and is deemed to capture changes in cognitive processes, even when the individual is unaware of these changes or is unable to verbalise them (Antonenko et al., 2010). The use of EEG to assess the cognitive load associated with processing contextual priors during action anticipation in sport may provide novel insights; insights which could have practical ramifications with regard to the utility of contextual priors under cognitively demanding performance conditions. Furthermore, a comparison of this technique with subjective retrospective reports may have important methodological implications for the assessment of cognitive load in sport.

2.4.2 Judgement utility. When making anticipatory judgements, it has been deemed that not only do people take into account the reliability of prior and current sources of information to inform their judgements; Bayesian theory postulates that the concept of utility also plays a role when trying to explain how people interact with the world around them (Vilares & Körding, 2011). Typically, researchers have discriminated procedural utility from judgement utility. The former refers to the costs and rewards associated with the strategies employed in order to solve a task (e.g., the expected energetic costs of carrying out a particular movement; Körding & Wolpert, 2006). The latter refers to the costs and rewards associated with the consequences of one's judgements: high judgement utility is associated with high rewards when accurate and low costs when inaccurate, and vice versa. For example, the doctor's joint assessment of the reliability conveyed by medical records and observed symptoms may suggest that Disease A is more likely than Disease B. However, Disease B may be expected to bring about more severe consequences for the patient than Disease A and, as such, diagnosing the former would be associated with higher rewards (if correct) and lower costs (if incorrect), compared to diagnosing Disease A (see Figure 2.3). According to Bayesian theory, the weighted average of the reliability conveyed by prior and current sources of information is convolved with the utility values assigned to possible judgements; the Bayes optimal final judgement is the one that maximises the probable utility (Geisler & Diehl, 2003).

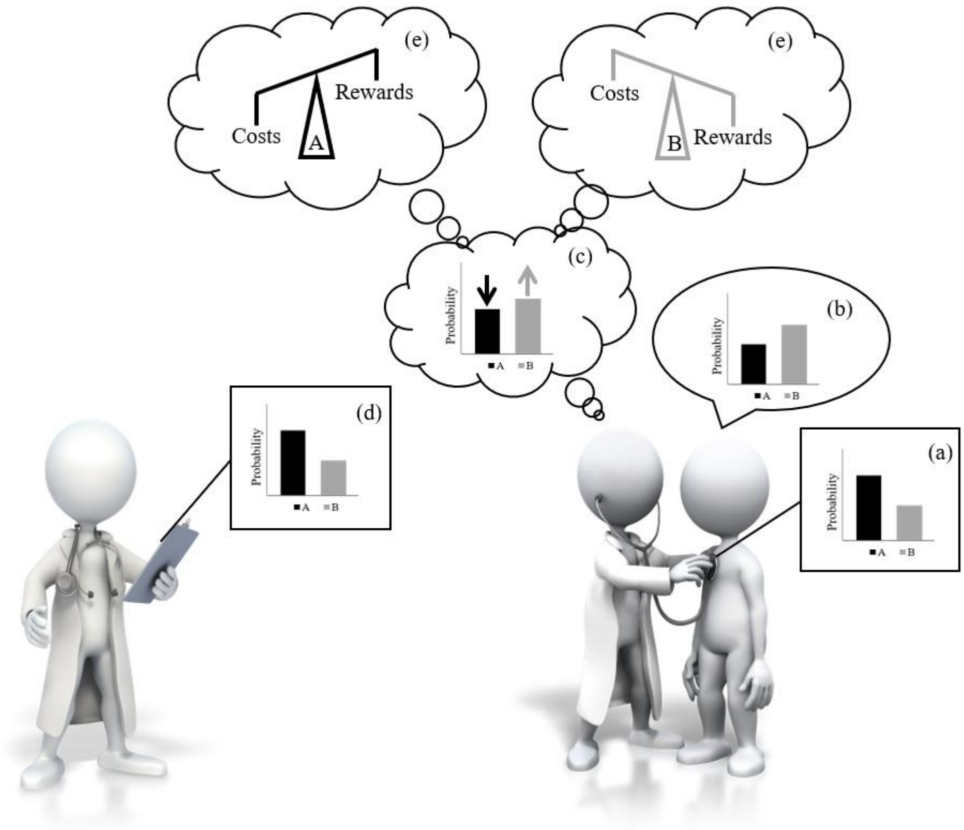

Figure 2.3. Doctor Weighing Judgement Utility Against Priors with Environmental Cues. The doctor takes into account the potential rewards (if correct) and costs (if incorrect) of diagnosing Disease A or B (e). The comparative utility of the two options affects the doctor's evaluation of medical records (d), measurable symptoms (a) and self-reported symptoms (b) and convolves the doctor's joint estimate (c) of the patient's clinical state.

It is noteworthy that the biasing effect of judgement utility is not only due to people's desire to gain rewards or avoid costs. The comparative utility of different judgements also influences people's estimations of the likelihood that specific outcomes will occur. Namely, people tend to overestimate the likelihood of an outcome happening, if prediction of that outcome is associated with higher utility. This biasing effect of judgement utility has been demonstrated across a variety of domains and contexts (see DeKay, Patiño-Echeverri, & Fischbeck, 2009; Russo & Yong, 2011). For example, Wallsten (1981) reported that physicians who were tasked with making diagnostic judgements assigned a higher probability to a patient having a malignant tumour than a cyst, despite the higher objective probability of a cyst. The author argued that the physicians overestimated the chances of a tumour due to the more severe consequences associated with a tumour, relative to a cyst. In other words, diagnosis of a tumour would be associated with greater rewards (if correct) and lower costs (if incorrect) than would diagnosing a cyst. One purported explanation for such a utility-driven estimation is that the individual infers the information at hand as more confirmative of the judgement associated with the highest utility than it should be (Russo & Yong, 2011).

This research suggests that the utility associated with different judgements seems to distort people's inference of the reliability conveyed by the information at hand and consequently biases their anticipatory judgement toward the option associated with comparatively higher utility. With regard to anticipation in sport, Canãl-Bruland, Filius, and Oudejans (2015) analysed the movement pattern of expert baseball batters on a batting task where they faced either fastballs (a faster type of pitch) or change-ups (a slower type of pitch). By analysing the batters' movement initiations, the authors proposed that the batters expected fastballs to occur more frequently than change-ups. It was proposed that expert batters use this strategy, as it enables them not only to handle the severe temporal constraints of facing a fastball, but also to slow down their swing if confronted with a change-up. Conversely, expecting a change-up would not allow the batter to catch up with the speed of a fastball – which would clearly impair their performance. This finding suggests that judgement utility (e.g., higher utility of predicting a fastball than a change-up in baseball) may bias athletes' anticipatory judgements, but the extent to which it modulates the effects of contextual priors, and athletes' processing priorities, during task performance is yet to be explored.

2.5 Thesis Rationale

The literature reviewed in this chapter suggests that athletes use contextual priors and evolving visual information to inform their judgements (e.g., Broadbent et al., 2018; Loffing et al., 2015; Mann et al., 2014) and the processing strategies employed (Runswick et al., 2018a) during anticipation task performance. In keeping with Bayesian theory (see Vilares & Körding, 2011), it seems that athletes integrate contextual priors with visual information on the basis of the comparative reliabilities of available information sources. That is, greater weight is given to sources that convey more reliable information, and vice versa (Gray & Cañal-Bruland, 2018). Furthermore, the reliabilities assigned to both contextual priors and various sources of visual information may change over time and appear to be modulated by the athlete's ability to infer the relevance of available information (e.g., Runswick et al., 2018a; Runswick et al., 2018b; Savelsbergh et al., 2002). Due to increased conditional inference of causal relationships between task features and increased top-down attentional control, it is reasonable to surmise that integration of contextual priors with visual information would increase cognitive load (De Neys et al., 2002; Kaplan & Berman, 2010; Waldmann & Hagmayer, 2001) and, consequently, that the impact of contextual priors would decline when the task load exceeds the limited capacity of working memory (see Paas et al., 2003). However, according to retrospective self-reports, the integration of contextual priors does not seem to come with increased cognitive load (Broadbent et al., 2018; Runswick et al., 2018a; Runswick et al., 2017) and, as such, the impact of contextual priors does not seem to decline with increasing task load (Runswick et al., 2018a). Finally, the utility associated with people's judgements is likely to distort their inference of the reliability conveyed by the information at hand (Russo & Yong, 2011) and seems to bias athletes' anticipatory judgements in favour of high-utility options (Canãl-Bruland et al., 2015).

In the current thesis, I aimed to address several limitations and gaps in the existing literature. Specifically, the assumption that athletes use reliability-based strategies to integrate contextual priors with evolving visual information over time is yet to be explored in information-rich environments (e.g., multi-player scenarios), where the informativeness of contextual priors fluctuates according to evolving visual information. Furthermore, the extent to which the effect of congruency between contextual priors and visual information is modulated by the reliability of such information has largely been ignored. With regard to the impact of contextual priors on cognitive load, previous research has relied on athletes' retrospective self-reports of cognitive load, whereas the applicability of online psychophysiological measures, such as EEG, is yet to be examined. Finally, the extent to which judgement utility modulates the impact of contextual priors on athletes' anticipatory judgements, and their processing priorities employed during task performance, has been overlooked in the existing literature.

In a series of four studies, I employed a representative video-based anticipation task simulating 2-versus-2 defensive soccer scenarios, in which players were required to predict the imminent actions of an oncoming opponent – with and without explicit provision of contextual priors pertaining to the opponent's action tendencies. In contrast to previous research, the players had to integrate evolving visual information in order to use the contextual priors. In the first study, I examined skill-level differences in anticipation performance and the extent to which explicit contextual priors impacted performance and the processing strategies employed during the task. I collected online measures of their anticipatory judgements and distribution of visual dwell time during task performance, as well as retrospective self-reports of cognitive load. In the second study, I altered the strength of the opponent's action tendencies and, via progressive temporal occlusion, the availability of relevant kinematic information. This enabled me to explore the extent to which the reliabilities associated with explicit contextual priors and evolving visual information affected expert players' anticipatory judgements. In the third study, I further explored the impact of explicit contextual priors on expert players' cognitive load. In addition to retrospective self-reports, I collected online psychophysiological data (EEG) as an index of cognitive load during task performance. I also examined the extent to which the effects of explicit contextual priors on performance were modulated by task load. In the fourth study, I explored how judgement utility influenced expert players' anticipatory judgements and, via immediate retrospective verbal reports of thoughts, their reliance upon explicit contextual priors and evolving visual information during task performance.

I expect that, by enhancing our understanding of these matters, we will be in a stronger position to make practical recommendations with regard to the utility of providing explicit contextual priors under various performance conditions and to athletes of different skill levels. The novelty of the task used in this series of studies, where the players have to account for unfolding visual information in order to use the contextual priors, may have methodological implications for the assessment of the temporal integration of contextual priors and visual information in dynamic performance environments. Furthermore, the original application of EEG for determining the cognitive load associated with processing contextual priors may provide valuable insights with regard to the validity of using objective online measures of cognitive load, compared to subjective retrospective reports typically used within the sporting domain. Finally, by examining the assumptions held by Bayesian models for probabilistic inference, the present research programme may contribute to the development of an overarching theoretical framework that can predict athletes' anticipatory behaviours under various performance conditions.

Chapter 3: The Impact of Explicit Contextual Priors on Experts' and Novices' Anticipatory Processes

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3.1 Abstract

Our understanding of how athletes integrate contextual priors with emergent visual information during action anticipation is limited. In this study, a soccer-based anticipation task was used to examine the ability of expert and novice players to combine explicit contextual priors pertaining to an opponent's action tendencies with pertinent unfolding visual information. Gaze behaviours and online anticipatory judgements were recorded during task performance. Moreover, the players' ultimate anticipatory judgements were assessed and retrospective ratings of their perceived levels of cognitive load were collected. Results showed that the explicit contextual priors biased the allocation of overt visual attention and shaped the ongoing judgements in experts, but not novices, without affecting their perceived levels of cognitive load. When the final action was congruent with the most likely action given the opponent's action tendencies, explicit contextual priors improved the ultimate judgements for both groups. For incongruent trials, the explicit priors had a negative impact on the ultimate judgements of novices, but not experts. These results were interpreted using a Bayesian framework to provide novel insights into how contextual priors and dynamic visual information are combined during action anticipation in sport. Moreover, the study provides evidence that this integration is governed by the relevance of the information at hand as well as the athlete's ability to infer this relevance.

3.2 Introduction

The ability to successfully anticipate the forthcoming actions of opponents is thought to be a key characteristic of expertise in many sports (Williams et al., 2011). Due to prolonged periods of domain-specific experience and practice, it is deemed that expert athletes have become more attuned to, and therefore more effective in their acquisition of, relevant visual cues available in the performance environment (Williams & Ford, 2008). This, in turn, enables them to anticipate faster and more accurately than their less skilled counterparts (Mann et al., 2007). In recent years, researchers have taken a broader focus when examining the nature of expert anticipation in sport, including the impact of non-visual information, such as contextual priors (Cañal-Bruland & Mann, 2015). Contextual priors, in the form of explicit provision of prior information about forthcoming opponents' action tendencies, have today become a vital part of the preparation process in elite sport. However, our understanding of the effects that this information may have on performance, and underlying perceptual and cognitive processes during action anticipation, is limited. In the current study, a video-based soccer task was used to assess the impact of explicitly provided contextual priors on the processes and strategies used by expert and novice players during action anticipation.

In the literature there is ample evidence that expert athletes are more able than novice athletes at extracting task-relevant visual information to predict opponents' forthcoming actions (for review, see Mann et al., 2007). For example, using a video-based task simulating 11-versus-11 defensive soccer scenarios, Roca and colleagues (2011) demonstrated that expert soccer players were more accurate than novice players in anticipating the next move of an opponent in possession of the ball. In addition to anticipation performance, the authors used a mobile eye-tracker in order to record the players' allocation of overt visual attention during performance. These gaze data revealed that expert players devoted more attention toward the players off the ball and less attention toward the opponent in possession, compared to their less skilled counterparts. This eye-tracking technique was also employed in a study by Savelsbergh and colleagues (2002) in which expert and novice soccer goalkeepers had to anticipate the direction of forthcoming penalty kicks. The authors reported that experts attended to more task-relevant visual information, such as the non-kicking leg of the penalty taker (see Franks & Hanvey, 1997), to a greater extent than novices. It was inferred that expert goalkeepers engaged in more sophisticated acquisition of advance visual information, which enabled them to anticipate with greater accuracy than novice goalkeepers.

It has been shown that expert athletes are not only superior to novice athletes in using advance visual cues to inform their anticipatory judgements. Even in the absence of reliable visual information, it has been demonstrated that experts are able to anticipate with greater accuracy than novices (Abernethy et al., 2001; Triolet et al., 2013). Under such conditions, it is proposed that athletes use contextual priors to inform their anticipatory judgments. However, it is worth noting that the integration of contextual priors does not necessarily generate greater anticipation performance. Using a video-based anticipation task, Loffing and colleagues (2015) showed that exposure to an opponent's previous action patterns biased expert, more so than novice, volleyball players' anticipation of the opponent's next action. Specifically, reliance upon the opponent's prior action tendencies resulted in faster and more accurate judgments when the to-be-anticipated action was congruent with the preceding pattern, compared to when it was not. Such congruency effect induced by the reliance on prior action tendencies has also been demonstrated in the anticipation performance of handball goalkeepers as they predicted the direction of forthcoming penalty throws (Mann et al., 2014).

In neither of these studies (Loffing et al., 2015; Mann et al., 2014) did the athletes receive explicit instructions or guidance pertaining to the opponents' action tendencies. However, in a study by Broadbent and colleagues (2018), expert soccer players were explicitly primed with the exact probabilities for whether an oncoming opponent would pass or dribble the ball to the left (65% chance) or to the right (35% chance). When the players received this information, they predicted the direction of the opponent's forthcoming actions more accurately on congruent trials (i.e., leftward outcomes). However, while a trend toward a detrimental performance effect was found for incongruent trials (i.e., rightward outcomes), the authors proposed that the players used conflicting kinematic information from the oncoming opponent, in order to suppress the detrimental effects that reliance on the opponent's action tendencies might have brought about. The assumption that the impact of contextual priors is moderated by athletes' reliance on kinematic information is supported by gaze data reported in a study by Navia and colleagues (2013). In a study where expert soccer goalkeepers had to predict the directions of forthcoming penalties, the authors observed that goalkeepers who spent relatively less time attending to the penalty taker's kinematics were more affected by explicit contextual priors pertaining to the penalty taker's action tendencies.

Such weighted reliance upon contextual priors and evolving visual information aligns with Bayesian models for probabilistic inference. According to Bayesian theory, people inform their anticipatory judgements based on probabilistic *if-then* relationships between the informational variables at hand and an unknown to-be-anticipated variable (i.e., *if* 'X' occurs, *then* there is a certain probability that 'Y' will occur). When integrating multiple informational variables, the observer evaluates available sources of information on the basis of their comparative reliability with regard to elucidating the to-be-anticipated variable; more weight is given to sources that are more reliable (Vilares & Körding, 2011). Such conditional integration of information has been demonstrated for simple and generic sensorimotor tasks, not only with regard to the integration of various sources of visual information (e.g., Hillis et al., 2004; Jacobs & Fine, 1999; Knill & Saunders, 2003) but also in relation to the integration of prior and current sources of information (e.g., Brouwer & Knill, 2009; Miyazaki et al., 2005; Tassinari et al., 2006). It has been suggested that Bayesian models for probabilistic inference may enable researchers to explain the strategies by which athletes weight various sources of information over time during action anticipation (Loffing & Cañal-Bruland, 2017).

In the aforementioned study by Savelsbergh and colleagues (2002), the authors analysed goalkeepers' eye movements for different stages of the penalty kick. It was revealed that their visual attention shifted from the penalty taker's upper body toward his lower body and the ball, as the point of foot-ball contact approached. This finding suggest that the goalkeepers adapted their processing priorities over time, as lower-body cues, such as non-kicking leg, kicking foot, and ball arguably conveyed more reliable information closer to the point of action. With regard to athletes' reliance upon contextual priors versus evolving visual information, it has been demonstrated that batters in both baseball (Gray & Cañal-Bruland, 2018) and cricket (Runswick et al., 2018b) reduced their reliance upon contextual priors as visual information in form the kinematic cues and the ball became more reliable (i.e., closer to the ball release from the pitcher/bowler). In the study by Runswick and colleagues (2018b), it was revealed that the batters' reliance upon contextual priors (during the early stages of run-up) and relevant visual information (around ball release) was more pronounced in experts, compared to novices. While these findings suggest that athletes may use reliability-based strategies to integrate various sources of information over time, it is worth highlighting the lack of dependency between contextual priors and visual information in the studies by Gray and Cañal-Bruland, (2018) and Runswick and colleagues (2018b). That is, athletes could use contextual priors to directly inform their judgements, without taking any visual information into account. However, in highly dynamic performance contexts, the dependency between contextual priors and progressively evolving visual information may be a vital component that researchers should consider when examining athletes' anticipatory processes under such conditions; for example, in soccer.

It has been suggested that increased conditional inference of causal relationships relevant to the task (e.g., integrating a priori *if-then* rules) may come with increased cognitive load (De Neys et al., 2002; Waldmann & Hagmayer, 2001). Furthermore, it is deemed that top-down attentional processes, which are driven by the individual's prior knowledge and beliefs (e.g., awareness of an opponent's action tendencies), are more cognitively demanding, than bottom-up, stimulus driven, attentional processes (Kaplan & Berman, 2010). Thus, it could be assumed that integrating contextual priors during anticipation might come with increased levels of cognitive load. This assumption was tested in the study by Broadbent and colleagues (2018). The authors collected retrospective reports of the levels of cognitive load that expert soccer players felt they had invested when trying to predict an oncoming opponent's next move. In contrast to predictions, explicit provision of contextual priors pertaining to the opponent's action tendencies did not alter players' perceived cognitive load (see also, Runswick et al., 2018a; Runswick et al., 2017). This finding may be explained by the fact that, in order to use the contextual priors, the players did not have to devote any cognitive resources to integrate them with evolving visual information; however, this potential explanation needs to be further explored.

In the current study, a video-based anticipation task was used to create simulated 2-versus-2 defensive soccer scenarios in which expert and novice players had to predict the direction (left or right) of an oncoming opponent's imminent actions – with and without explicit provision of contextual priors pertaining to the opponent's action tendencies (dribble = 67%, pass = 33%). Importantly, in the current task, the players had to incorporate evolving visual information in order to use the contextual priors. Skill-level differences in anticipation performance, and the extent to which explicit contextual priors affected performance and the processes by which players integrated explicit contextual priors and visual information over time, were examined. Online measures of the players' anticipation accuracy and distribution of visual dwell time were collected during task performance, as was the efficiency of their ultimate anticipatory judgement. Additionally, players' retrospective self-reports of their cognitive load invested during the task were collected. The findings were evaluated against Bayesian models for probabilistic inference, to offer a novel insight into the strategies by which athletes integrate contextual priors and evolving visual information during action anticipation.

It was predicted that the explicit provision of contextual priors would reinforce top-down attentional control (Torralba, 2003) and, as such, bias the players' allocation of overt visual attention toward information that enabled them to use the contextual priors (i.e., the players off the ball; see Methods section for detailed explanation). It was expected that the players would use this information to inform the anticipatory judgements they held during task performance. This effect would be expressed by increased online anticipation accuracy on trials where the opponent dribbled the ball (i.e., congruent trials) and decreased online anticipation accuracy when the opponent passed the ball to his teammate (i.e., incongruent trials; cf. Loffing et al., 2015; Mann et al., 2014; Navia et al., 2013). Furthermore, it was expected that the impact of explicit contextual priors would be more pronounced in experts than in novices (cf. Loffing et al., 2015; Runswick et al., 2018a). In keeping with Bayesian theory (see Vilares & Körding, 2011), it was predicted that the impact of explicit contextual priors would decrease as the reliability of the opponent's kinematic information increased – i.e., in the latter stage of each trial. Specifically, due to their superior ability to extract advance visual information (see Mann et al., 2007), it was predicted that experts, would be more able than novices at integrating unfolding kinematics with contextual priors, in order to refine their ultimate anticipatory judgement. This would be observed in the finding that the explicit provision of contextual priors would enhance anticipation efficiency on congruent trials for both experts and novices, whereas on incongruent trials it would impair the anticipation efficiency for novices, but not experts. As such, it was predicted that experts would outperform novices on the anticipation task, as manifested in superior anticipation efficiency on both congruent and incongruent trials. With regard to cognitive load, the primary prediction was that the explicit provision would not elevate perceived cognitive load (cf. Broadbent et al., 2018). However, there was also the possibility that, due to the novelty of the experimental task, integrating contextual priors with evolving visual information would increase perceived levels of cognitive load.

3.3 Methods

3.3.1 Participants. A total of 16 expert (M_{age} = 20 years, *SD* = 2) and 15 novice (M_{age} = 21 years, *SD* = 3) male soccer players participated. A spreadsheet for estimating sample size for magnitude-based inferences (Hopkins, 2006) was used to calculate the number of participants required to find a clear effect (i.e., chances of the true effect to be substantially positive and negative < 5%; Batterham & Hopkins, 2006) on our main dependent measure (anticipation efficiency). I used data from a previous study (Roca et al., 2013) to calculate the minimum required sample size (Hopkins, Marshall, Batterham, & Hanin, 2009). This sample size is comparable to those employed in previous studies examining the perceptual and cognitive mechanisms that underpin anticipation performance across expert and novice athletes (e.g., Jackson et al., 2006; Murphy et al., 2016; Roca et al., 2013). The expert players had an average of 11 years (*SD* = 2) of competitive experience in soccer and took part in an average of 8 hours (*SD* = 3) of practice or match-play per week. The novice players were not currently playing at a competitive level and had an average of 2 years (*SD* = 2) of competitive experience. College of Health and Life Sciences Research Ethics Committee approval was obtained prior to data collection (see Appendix 2). The study conformed to the recommendations of the Declaration of Helsinki and written informed consent was obtained from all participants.

3.3.2 Test stimuli. The video sequences were filmed on an artificial turf soccer pitch using a wide-angle converter lens (Canon WD-H72 0.8x, Tokyo, Japan) attached to a high-definition digital video camera (Canon XF100, Tokyo, Japan). The video camera was attached to a moving trolley, at a height of 1.7 m, to closely replicate the perspective of a central defender in a typical match situation.

The sequences represented 2-versus-2 counter attacking scenarios in soccer. In each sequence, there was one attacking player in possession of the ball (termed 'the opponent' from here on), a second attacker off the ball, and one defender marking the second attacker. Participants viewed all sequences from a first-person perspective, as if they were the second defender (see Figure 3.1). This scenario rapidly unfolds and presents a high level of perceived threat, which requires athletes to make frequent anticipatory behaviours (Triolet et al., 2013) and to increase their use of prior expectations (Roca et al., 2013), when compared to less pressured situations.

At the start of each sequence, the opponent was positioned 3 m inside the halfway line, approximately 7 m in front of the participant. The attacker off the ball and the marking defender started approximately 3 m behind, either on the left, or the right, side of the player in possession. As players in a soccer match are normally aware of the relative positions of the ball and other players when they perform such tasks, each sequence started with a 1-s freeze-frame, to allow the participant to determine this information (cf. Roca, et al., 2011). When the sequence started, the players approached the participant and, after approximately 1.5 s, the attacker off the ball made a direction change towards either the left or the right. At the end of the sequence, the opponent was positioned approximately 3 m in front of the participant. The attacker off the ball was level with the opponent, either to his left or right. The marking defender followed the attacker off the ball throughout each sequence. At the end of each sequence, the opponent either passed the ball to his teammate (33% of trials) or dribbled the ball in the opposite direction (67% of trials). The final position of the players off the ball was therefore informative with regard to the direction of the final action (i.e., if the players off the ball were on the left side, 67% of the opponent in possession's final actions were to the right, and vice versa). A sequence lasted 5 s and was occluded 120 ms after the opponent's final action.

The footage was edited using Pinnacle Studio software (v15; Pinnacle, Ottawa, Canada). In total, 130 video simulations were created. Two qualified soccer coaches (UEFA A Licence holders) independently selected the clips that they considered to be representative of actual game play. Only the clips that were selected by both coaches were included in the final test footage, making a total of 48 clips. These clips were projected onto a 4.1 x 2.3 m projection screen (AV Stumpfl, Wallern, Austria) using an NEC PE401H projector (NEC, Tokyo, Japan).

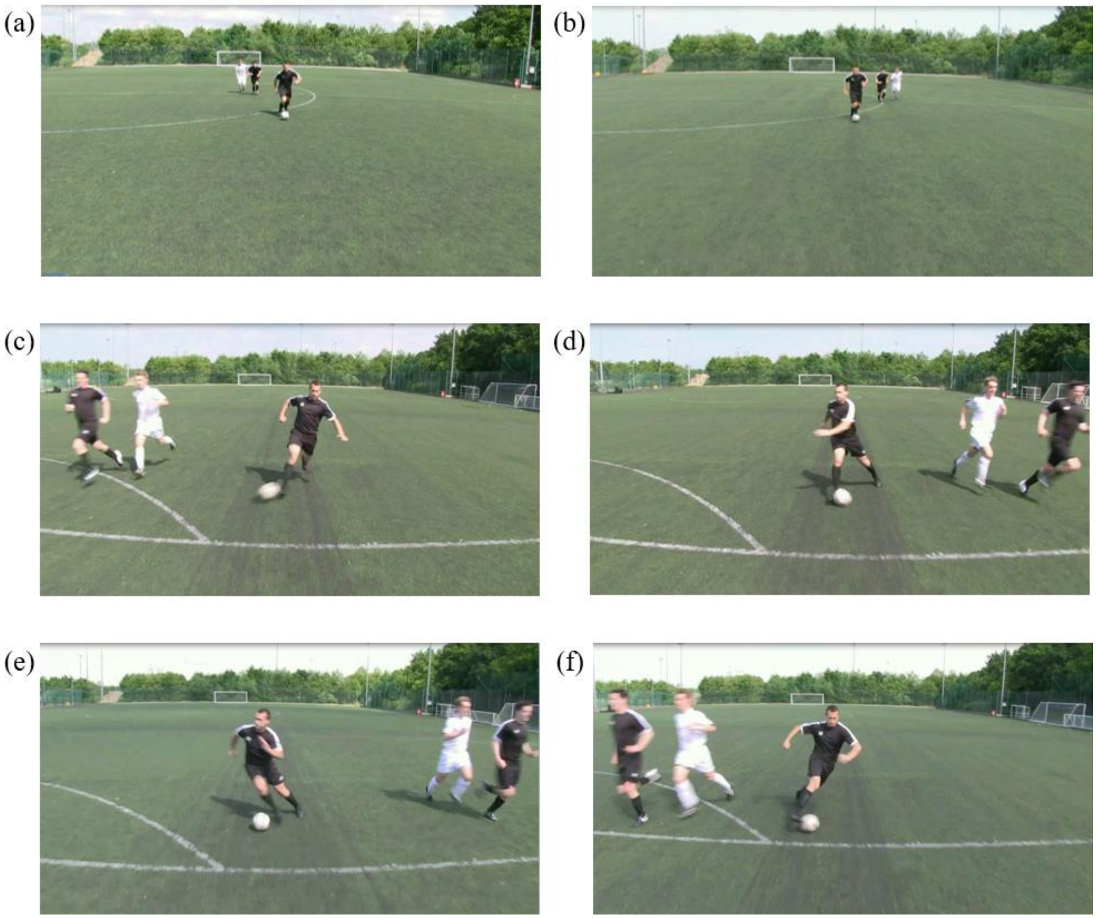

Figure 3.1. Test Stimuli. The two different positions that the players off the ball could have at the start of each sequence; left-hand side of the opponent (a) and right-hand side of the opponent (b). The four different ultimate actions that the opponent could carry out at the end of each sequence; pass left (c), pass right (d), dribble left (e), and dribble right (f).

3.3.3 Task design. The task for the participant was to predict the direction (left or right) of opponent's final action. Also, over the course of each trial, the participant was required to indicate their ongoing anticipatory judgements with regard to the direction of the final action. At the start of each trial, the participant was positioned 4 m from the projection screen holding a bespoke response device in each hand (see Figure 3.2a). The device was equipped with two response buttons; one to record the participant's online judgements throughout each trial and one to record their ultimate judgement on each trial (see Figure 3.2b). The participant was instructed to indicate their online judgements as soon as they started to feel that one direction was more likely than the other, and that they could change these judgements throughout the trial. The participant was instructed to execute their ultimate judgement as soon as they were certain enough to carry out an action based on their prediction; they were told that they could not change this response. The response time for their ultimate judgement was displayed on-screen after each trial. As the sequence was occluded 120 ms after the opponent's final action, the participant was able to see whether their response was correct or incorrect. The participant was free to move as they preferred during the task performance in order to maximise the real-world representativeness of the task (cf. Roca et al., 2011).

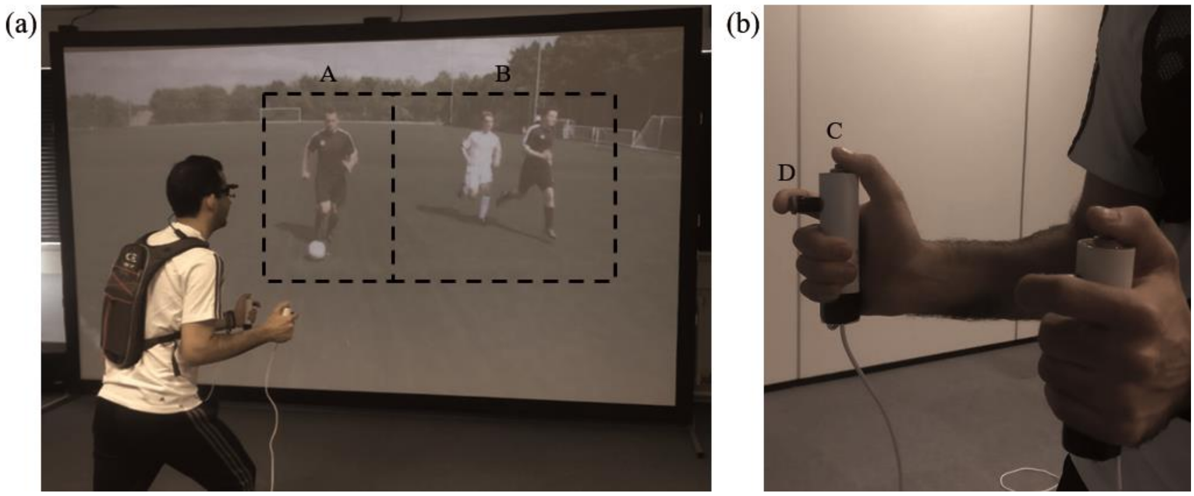

Figure 3.2. Experimental Setup. Depiction of the experimental task with areas of interest superimposed (A = opponent; B = players off the ball; Note: These markings were not visible to the participant; a). Close-up of handheld devices with response buttons (C = online judgements; D = ultimate judgement; b).

3.3.4 Procedure. Prior to testing, the participant was given an overview of the experimental protocol and was presented with two blocks of six trials in order to familiarise themselves with the experimental setup and the response requirements. The participant was then fitted with a lapel microphone and a body-pack transmitter that was wirelessly connected to a compact diversity receiver (ew112-p G3; Sennheiser, Wedemark, Germany) and a recording device (Zoom H5; Zoom Corporation, Tokyo, Japan), so that self-report data could be recorded. Eye-tracking glasses (Applied Science Laboratories, Bedford, MA, USA) were subsequently fitted onto the participant's head. The glasses were connected to a recording device that was worn by the participant in a small backpack. The eye-tracking system was calibrated using a 9-point grid that covered the entire display. Calibration was checked between conditions and recalibration was performed where necessary.

After the calibration of the eye-tracking system, the 48 test trials were presented under two informational conditions (i.e., 96 trials in total). Each condition of 48 trials was divided into six blocks and each block comprised eight trials. In one condition (*EXP*), contextual priors relating to the opponent's action tendencies (dribble = 67%, pass = 33%) were explicitly announced prior to each block, both verbally and on-screen. In the other condition (*CTRL*), no contextual priors were explicitly provided; however, the proportion of actions was the same as in the condition with explicit contextual priors (i.e., dribble = 67%, pass = 33%). The order in which conditions were presented was randomised and counterbalanced across skill groups (i.e., half of the expert group and half of the novice group began with the condition containing explicit contextual priors while the other half began without priors). To eliminate the influence of trial-specific characteristics, the same 48 trials were presented in both informational conditions. However, to avoid any potential familiarity between conditions, the trial order in each condition was randomised. Upon completion of each block, the participant was asked to indicate their perceived level of cognitive effort when completing the trials in the preceding block, using the RSME (Zijlstra, 1993). In order to minimise the influence of the experimental manipulations on data collected in the subsequent condition, a washout condition comprising three blocks of six trials was carried out between each test condition. Prior to each of the three washout blocks, novel information about the opponent's action tendencies was explicitly provided (dribble = 40%, pass = 60%; dribble = 60%, pass = 40%; dribble = 50%, pass = 50%, in this order). This information corresponded to the proportion of dribbles and passes that the opponent performed within each block of the washout condition. The entire test session was completed in 60 minutes.

3.3.5 Dependent measures

3.3.5.1 Visual dwell time. The allocation of overt visual attention was characterised as the relative distribution of visual dwell time across two interest areas: the opponent, and the players off the ball (see Figure 3.2a). Dwell time distributions have previously been used as an index of visual attentional allocation (e.g., Navia et al., 2013; van der Kamp, 2011). The three most discriminating congruent and incongruent trials based on combined within-group effects of explicit contextual priors on anticipation efficiency, making it six trials for each condition and participant (i.e., 372 trials in total), were subjected to gaze analysis[1]. Only the most discriminating trials based on performance outcomes were selected in order to provide the most sensitive measure of how well the variable of interest (in this study: visual dwell time) predicts the performance measure of interest (in this study; anticipation efficiency; Ericsson & Smith, 1991). This is an established approach when assessing the perceptual or cognitive mechanisms that underpin performance effects (e.g., Martins, Garganta, Oliveira, & Casanova, 2014; Murphy et al.,2016; Roca et al., 2013). The data were analysed frame-by-frame using Windows Media Player version 12 (Microsoft Corporation, WA, USA). Visual dwell time outside the classified interest areas (< 0.6%) and missing data due to equipment failure (< 1.1%) or trials in which invalid button presses were made (< 2.5%) were excluded from the gaze analysis. Also, trials for which more than 20% of the data were missing (< 2.2%) were excluded. The first author analysed all trials. A random sample containing 10% of all data was reanalysed to obtain intra- (96%) and interobserver (92%) reliability. In the case of the latter, the data were re-coded by an independent researcher.

3.3.5.2 Online anticipation accuracy. The accuracy of online anticipatory judgements was expressed as the correspondence of the participant's button presses to the direction of the final action. All responses of online anticipation that the participant made over the course of a trial were included in the average accuracy score that was calculated for each condition. Trials for which response times differed by more than three *SD*s (< 0.3%) from the participant's mean response time were deemed to be invalid button presses and were excluded from the analysis.

3.3.5.3 Anticipation efficiency. To account for any speed-accuracy trade-off, the ultimate anticipatory judgement was expressed as an efficiency score for each informational condition (cf. Bishop, Kuhn, & Maton, 2014). The efficiency score was calculated by multiplying the mean response time by the proportion of inaccurate trials for the participant's ultimate judgements; lower efficiency score indicates superior anticipation efficiency. Responses executed after video occlusion (i.e., 120 milliseconds after foot-ball contact) were recorded as

[1]Gaze data from the trials chosen for analysis may not be representative of all trials (see the Discussion section for further comments on this).

inaccurate, since too little time would have been afforded for the participant to carry out a successful defensive action in response to the attack. Trials for which response times differed by more than three *SD*s from the participant's mean response time (< 1.2%) were deemed to be invalid button presses and were excluded from the analysis.

3.1.5.4 Cognitive Load. Perceived levels of cognitive load were expressed by the RSME ratings (cf. Broadbent et al., 2018; Runswick et al., 2018a; Runswick et al., 2017). The scale ranges from 0 to 150 and contains nine descriptors (e.g., 2 = absolutely no effort; 58 = rather much effort; 113 = extreme effort).

3.3.6 Data analysis. The impact of explicit contextual priors on the dependent measures (EXP−CTRL) was evaluated within each skill-group. If both experts and novices exhibited substantial effects of the same sign (i.e., *increase* or *decrease*) for a certain dependent measure, then the effect magnitudes were compared across skill groups. Since it was predicted that attentional allocation would change as the opponent's kinematics became more reliable, visual dwell time was analysed for each trial in its entirety (0-5 s), as well as for the first (0-2.5 s) and second (2.5-5 s) halves of the trial, separately. As I predicted a congruence effect for online anticipation accuracy and anticipation efficiency, both combined and separate analyses of congruent and incongruent trials were carried out for these dependent measures. In order to validate the test task as one capable of discriminating between performance of players of different skill levels, differences in anticipation efficiency across skill-groups were evaluated. To check whether information about the opponent's action tendencies was accrued due to familiarity to his preceding actions, the average scores for online anticipation and anticipation efficiency from the first three blocks in CTRL were compared to those obtained over the final three blocks in the same condition.

3.3.6.1 Statistical analysis. Descriptive statistics are reported as means and *SD*s. Magnitudes of observed effects are reported as standardised (*d*) and unstandardised units and uncertainties in true effects as 90% CIs. Effects were standardised by dividing the mean effect by the combined *SD* (Cumming, 2012). Observed effects were interpreted against the following scale: $0.2 > |d|$, trivial; $0.2 \leq |d| < 0.5$, small; $0.5 \leq |d| < 0.8$, moderate; $0.8 \leq |d|$, large (Cohen, 1988). Cohen's standardised unit for the smallest substantial effect (0.2) was used as a threshold value when estimating uncertainties in true effects. The following scale was used to convert the quantitative chances to qualitative descriptors: 25-75%, possible; 75-95%, likely; 95-99.5%, very likely (Hopkins, 2002). If the lower and upper bounds of the confidence interval exceeded the thresholds for the smallest substantial negative and positive effect, respectively (i.e., the chances for a substantial negative and a substantial positive effect were both > 5%), then the effect was deemed unclear. All other effects were reported as the magnitude of the observed value and were evaluated probabilistically as described above. We chose against using traditional null-hypothesis significance testing (Neyman & Pearson, 1933) in favour of magnitude-based inference (Batterham & Hopkins, 2006). The latter approach was chosen, as it is more informative to report magnitude of observed effects and precision of estimates than whether effects are statistically significant according to a specified alpha level (e.g., $p < .05$; Cumming, 2014; Wilkinson, 2014).

3.4 Results

3.4.1 Visual dwell time. As shown in Figure 3.3, expert players distributed less visual dwell time on the opponent in EXP, compared to in CTRL (d = 0.42 ±0.28). Conversely, they spent more time looking at the players off the ball in EXP than in CTRL (d = 0.47 ±0.26). No clear effects were found when novice players' distribution of visual dwell time was compared across conditions. Unstandardised effects between conditions for experts' and novices' distribution of visual dwell time are presented in Table 3.1. Separate analyses of the first and the second trial half revealed that experts' decrease in visual dwell time on the opponent and their increased attention toward the players off the ball emerged over the first half of the trial (d = 0.44 ±0.28 and d = 0.47 ±0.26, respectively), whereas no clear effects were yielded over the second half of the trial. For novices, the separate analyses of each trial half did not reveal any clear effects over any of the halves.

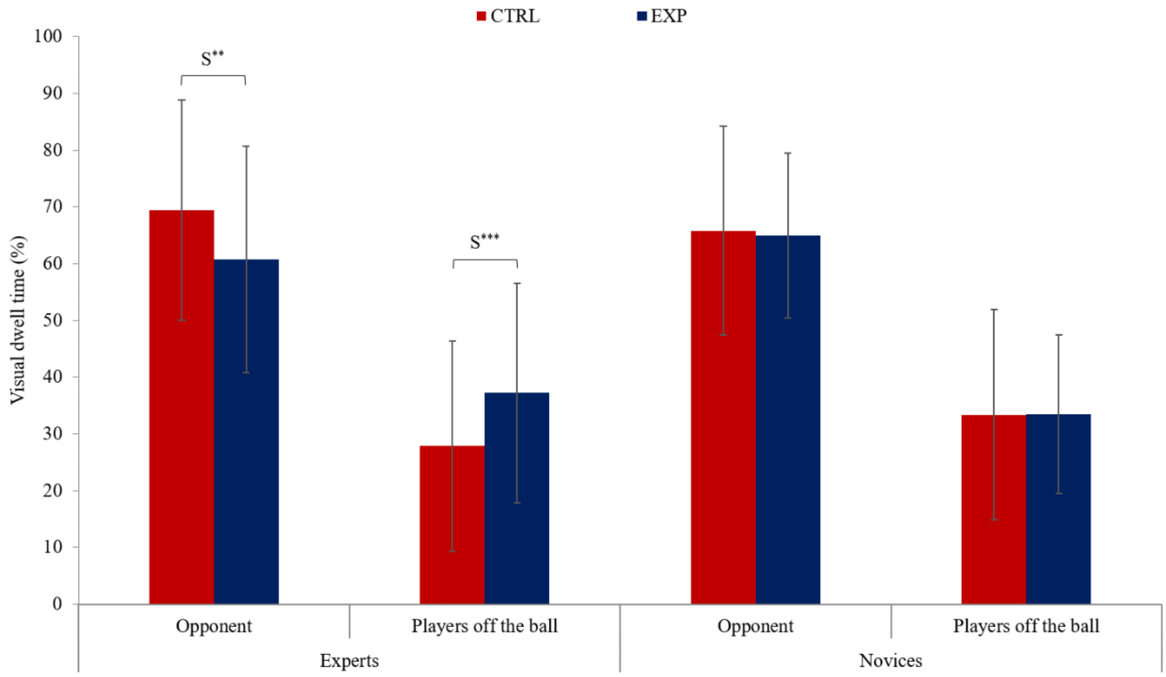

Figure 3.3. Visual Dwell Time. Group means and *SD*s for the distribution of visual dwell time across areas of interest in each condition, as well as inferences of observed and true effects between conditions. Inference of observed effects: $0.2 \leq |d| < 0.5$, small (S). Inference of uncertainty in true effects: ** likely (75-95%); *** very likely (95-99.5%).

3.4.2 Online anticipation accuracy. As illustrated in Figure 3.4, the overall accuracy of expert players' online anticipatory judgements was higher in EXP than in CTRL (d = 0.93 ±0.47). Separate analyses of congruent and incongruent trials showed that the accuracy was higher in EXP than in CTRL on congruent trials (d = 0.80 ±0.44), whereas it was lower in EXP than in CTRL on incongruent trials (d = 0.57 ±0.45). No clear effects between the two conditions were found for novice players. Unstandardised effects between conditions for experts' and novices' accuracy of online anticipatory judgements are presented in Table 3.1. To test for potential familiarity effects, the average accuracy score of the initial three blocks in CTRL was compared to the average score of the final three blocks in the same condition; however, no clear effects were yielded for any of the skill groups.

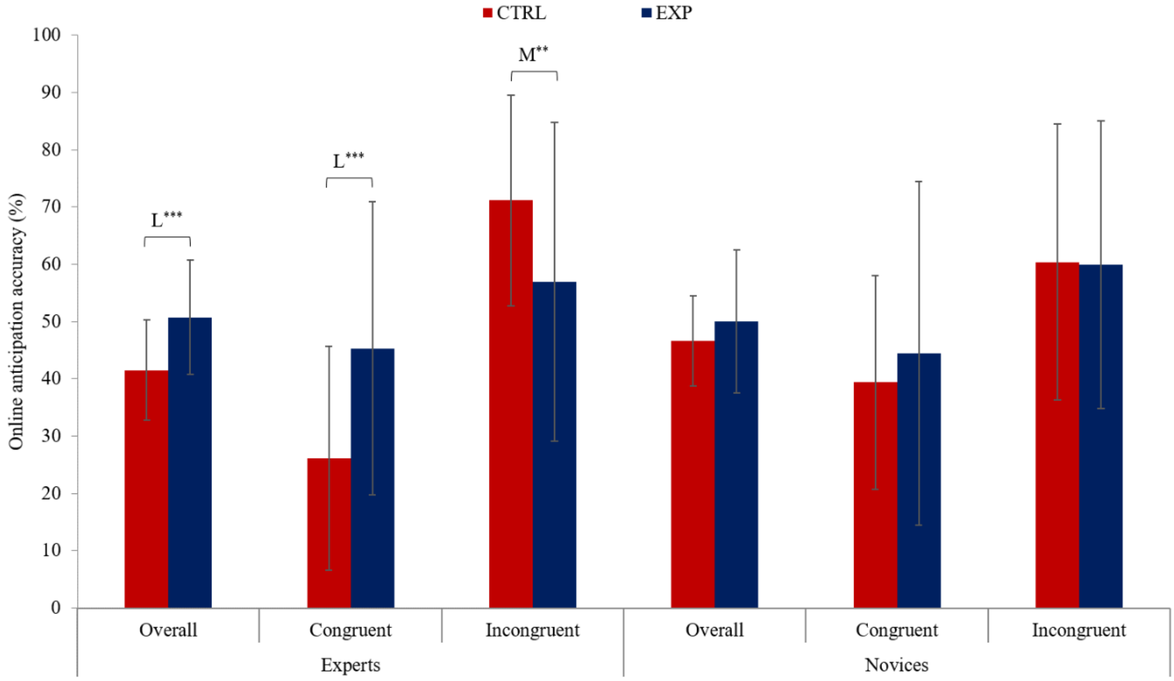

Figure 3.4. Online Anticipation Accuracy. Group means and *SD*s for the online anticipation accuracy in each condition, as well as inferences of observed and true effects between conditions. Inference of observed effects: 0.5 ≤ |d| < 0.8, moderate (M); 0.8 < |d|, large (L). Inference of uncertainty in true effects: ** likely (75-95%); *** very likely (95-99.5%).

3.4.3 Anticipation efficiency. The descriptive statistics for the response times and the accuracy scores that were used to calculate the anticipation efficiency scores are shown in Table 3.2. Figure 3.5 shows that expert players exhibited superior anticipation efficiency than novices, both in CTRL (overall, d = 1.01 ±0.60; congruent, d = 0.63 ±0.60; incongruent, d = 0.51 ±0.59) and in EXP (overall, d = 0.71 ±0.59; congruent, d = 0.39 ±0.60; incongruent, d = 0.77 ±0.59). For overall anticipation efficiency, both experts and novices were more efficient in EXP than in CTRL (d = 0.28 ±0.38 and d = 0.43 ±0.52, respectively), but no clear difference was obtained when the beneficial effect within each group were compared. On congruent trials, both experts and novices showed superior anticipation efficiency in EXP, compared to in CTRL (experts, d = 0.44 ±0.41; novices, d = 0.63 ±0.60), but no clear difference was found with regard to the magnitude of the effect within each group. On incongruent trials, explicit contextual priors had a greater effect on novices than experts (d = 0.20 ±0.52); there was a clear detrimental effect on novices' (d = 0.26 ±0.43), but not experts' (d = 0.02 ±0.35) anticipation efficiency, when EXP was compared to CTRL. Table 3.1 presents the unstandardised effects between conditions with regard to the anticipation efficiency scores exhibited by experts and novices. When the average efficiency score of the initial three blocks in CTRL was compared to the average accuracy score of the final three blocks in the same condition, no clear effects were obtained for neither experts nor novices.

Table 3.2

Descriptive Statistics (M ± SD) for Response Time and Accuracy of Ultimate Anticipatory Judgements for Experts and Novices

	CTRL		EXP	
	Experts	Novices	Experts	Novices
Response time (ms)				
Overall	4,437 ± 583	4,761 ± 210	4,303 ± 576	4,768 ± 198
Congruent	4,413 ± 577	4,735 ± 209	4,283 ± 562	4,745 ± 188
Incongruent	4,486 ± 598	4,812 ± 217	4,342 ± 611	4,816 ± 227
Response accuracy (%)				
Overall	54 ± 9	48 ± 9	57 ± 10	53 ± 10
Congruent	66 ± 14	61 ± 15	72 ± 10	70 ± 12
Incongruent	31 ± 20	23 ± 18	28 ± 20	18 ± 14

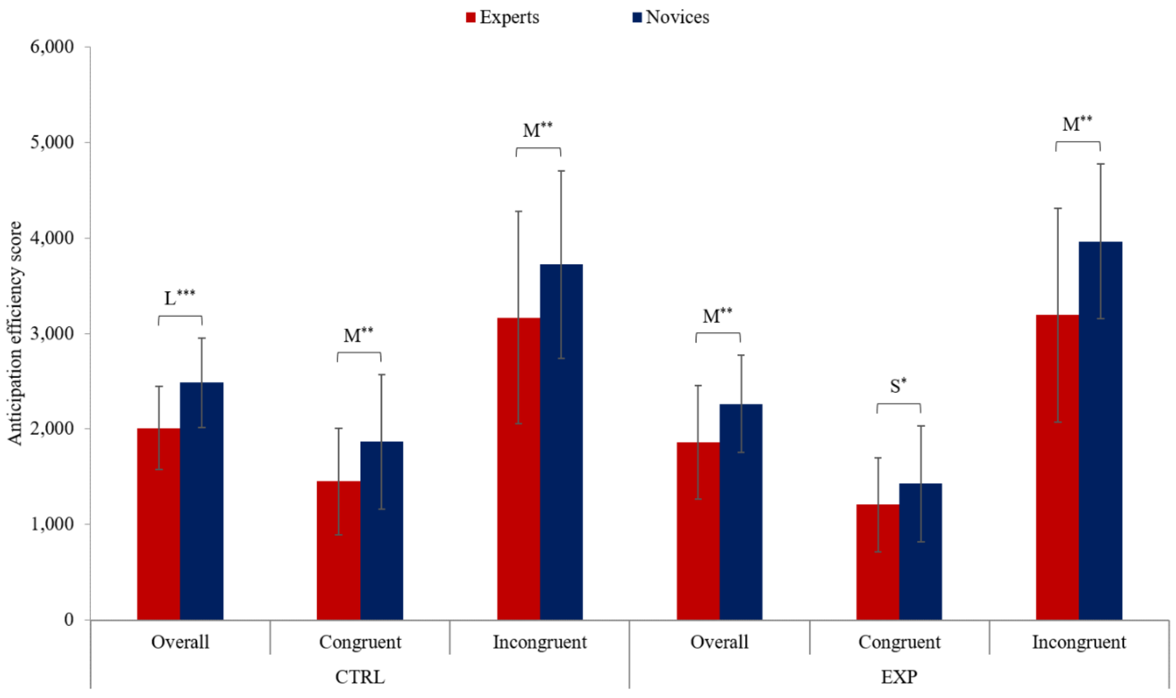

Figure 3.5. Anticipation Efficiency. Group means and *SD*s for the anticipation efficiency score in each condition, as well as inferences of observed and true effects between groups. (note: lower efficiency scores indicate superior anticipatory efficiency). Inference of observed effects: $0.2 \leq |d| < 0.5$, small (S); $0.5 \leq |d| < 0.8$, moderate (M); $0.8 < |d|$, large (L). Inference of uncertainty in true effects: * possibly (25-75%); ** likely (75-95%); *** very likely (95-99.5%).

3.4.4. Cognitive load. The ratings of perceived levels of cognitive load did not yield any substantial effects between CTRL (experts, 68 ± 21 [*M* ± *SD*]; novices, 73 ± 18) EXP (experts, 70 ± 25; novices, 69 ± 19), neither for experts (d = 0.08 ±0.15) nor novices (d = 0.17 ±0.16). Unstandardized effects between conditions for the RSME scores of expert and novice players are presented in Table 3.1.

Table 3.1

Unstandardised Effects (M ±90% CI) of Explicit Contextual Priors (EXP−CTRL) on Dependent Measures for Experts and Novices

	Experts	Novices
Visual dwell time (%)		
Opponent	−8.7 ± 5.7	−0.9 ± 5.6
Players off the ball	9.3 ± 5.3	0.1 ± 5.7
Online anticipation accuracy (%)		
Overall	9.2 ± 4.6	3.4 ± 6.4
Congruent	19.2 ± 10.6	5.0 ± 12.4
Incongruent	−14.2 ± 11.3	−0.4 ± 10.2
Anticipation efficiency score		
Overall	−152.0 ± 206.3	−223.4 ± 270.0
Congruent	−246.0 ± 225.9	−439.4 ± 413.8
Incongruent	25.7 ± 415.7	243.0 ± 410.6
Cognitive load		
RSME score	2.1 ± 3.7	−3.4 ± 3.1

Note: lower anticipation efficiency score indicates superior anticipation efficiency.

3.5 Discussion

The current study examined the impact of explicitly provided contextual priors on the processes and strategies used by expert and novice soccer players during action anticipation. Visual dwell time was used as a process measure to examine the players' attentional focus and subsequent pickup of ongoing visual information. Furthermore, the accuracy of their online anticipatory judgements and the efficiency of their ultimate anticipatory judgement were assessed. Additionally, retrospective self-reports were collected to investigate the players' perceived cognitive load during the task.

In line with the predictions, the explicit provision of contextual priors guided the expert players' visual attention toward visual information that enabled them to use the contextual priors. It is worth noting that this finding refers to analysis of the six most discriminating trials, according to the effect of explicit contextual priors on anticipation efficiency (cf. Martins et al., 2014; Murphy et al., 2016; Roca et al., 2013). While comparing these gaze data to those from all trials would be interesting from a methodological perspective, this was beyond the scope of this study. The expert players increased the time they spent looking at the players off the ball and decreased the time spent looking at the opponent, relative to when no contextual priors were explicitly given; this effect was not found for novice players. In the current study, the positioning of the attacker off the ball relative to the opponent (left side or right side) revealed information that enabled the players to use the contextual priors effectively (i.e., if the attacker off the ball was on the left side, 67% of the opponent's final actions were to the right, and vice versa). This information could be confirmed early in the trial as the attacker off the ball made his direction change ~1.5 seconds after trial onset. This finding supports the notions that contextual priors induce a more top-down, context-driven, selection of visual information (Eberhardt et al., 2004; Torralba, 2003) and that expert athletes are better able to utilise task-relevant visual information during performance than novices are (Roca et al., 2011; Savelsbergh et al., 2002).

Separate analyses revealed that the explicit contextual priors biased how expert players allocated their visual attention over the first half of the trial only. This temporal effect is in line with the prediction that the impact of explicit contextual priors would emerge predominantly over the first half of the trial, in which the direction change of the attacker off the ball occurred and the kinematic information from the opponent was not relevant to the final action. Furthermore, this finding concurs with previous research reporting that expert athletes adjust their allocation of visual attention (Savelsbergh et al., 2002) and relative reliance upon contextual priors and visual information (Runswick et al., 2018b) as the relevance of evolving visual information changes over time.

As predicted, the expertise effect on visual attention was mirrored in the online anticipatory judgements expressed by the players. With explicit priors, expert players enhanced the accuracy of their online judgements on congruent trials. On incongruent trials, the provision of priors decreased their accuracy of online judgements. However, I did not find these biasing effects for novice players. These findings are consistent not only with the dwell time data, but also with previous published research showing that expert athletes are more susceptible to contextual priors than novices (Loffing et al., 2015; Runswick et al., 2018a; Runswick et al., 2018b). It is worth noting that the expert players in our study were only biased by the opponent's action tendencies when information about these tendencies was explicitly provided. This finding suggests that, in contrast to previous research (Loffing et al., 2015; Mann et al., 2014), the players in our study were not able to utilise contextual information derived from task experience alone (i.e., from the opponent's actions on preceding trials).

An effect was also found for the explicit provision of contextual priors, but not for task experience alone, on the players' efficiency when making their ultimate judgements. In line with our predictions, the explicit provision of priors enhanced anticipation efficiency on congruent trials in both expert and novice players. In keeping with Bayesian theory, it is reasonable to assume that combining contextual priors and confirmatory kinematic information resulted in higher informational reliability and, consequently, superior anticipatory judgement, compared to when no contextual priors were explicitly provided. For experts, these findings correspond with the findings for visual attention and online anticipatory judgements, as well as previous published reports that have emphasised the beneficial impact of contextual priors on congruent trials (e.g., Broadbent et al., 2018; Loffing et al., 2015; Mann et al., 2014). It is noteworthy that the enhanced efficiency demonstrated by novices was not accompanied by any biases in their allocation of visual attention or online judgements. This finding suggests that novices ultimately used the contextual priors to guide their anticipatory judgements, but did not integrate them with current visual information to form and update their in-task expectations.

As predicted, on incongruent trials the explicit provision of contextual priors impaired the efficiency of the ultimate anticipatory judgement in novices, but not in experts. The lack of detrimental performance effect on expert players contradicts those reported by Loffing and colleagues (2015) and Mann and colleagues (2014). In keeping with Bayesian theory, we speculate that these contrasting effects could be due to the fact that the reliability of the opponent's kinematics may have varied across studies (i.e., different type of actions were to be anticipated at different time points). Specifically, we argue that the experts in our study used their superior ability to interpret opponents' kinematics (see Mann et al., 2007) in the final stages of the trial to update their prior expectations. This suggestion is supported by the notion that contextual priors is moderated by the athletes reliance upon pertinent visual information (Gray & Cañal-Bruland, 2018; Navia et al., 2013). However, in the studies by Loffing and colleagues (2015) and Mann and colleagues (2014), conflicting kinematic information unfolding on incongruent trials may have been occluded which disabled the athletes to refine their judgements. These findings suggest that the impact of contextual priors is governed by both the availability of relevant visual information and the performer's processing priorities of the available information. Future research is required to examine the impact of manipulating the reliability of the different information sources, potentially through the use of the temporal occlusion paradigm, to provide further support for the Bayesian model in this domain.

In support of Bayesian theory, we propose that, compared to novices, the expert players used a more optimal weighing of contextual priors and visual information resulting in superior efficiency of their ultimate anticipatory judgement on both congruent and incongruent trials. These findings may have practical implications, as recent advancements in technology have enabled sophisticated analyses of forthcoming opponents' action tendencies/movement patterns; hence, the provision of contextual priors has become a vital component of preparation in elite sport (Memmert et al., 2017). Specifically, this study provides novel evidence that the impact of explicitly providing such information is subject not only to the availability of visual information, but also the athlete's ability to use this information.

However, it is noteworthy that expert players obtained an average accuracy score of 57% for their final predictions, when contextual priors were explicitly provided. This is somewhat surprising as they would have obtained a score of 67%, if they had opted for the most likely direction, given the opponent's action tendencies, on all trials in this condition. One potential explanation for this is that the players might have felt obliged to engage with the task in a meaningful way; to have selected the 'dribble' option on each single trial could have been construed as impolite/uncooperative. It is possible that the objective probabilities conveyed by the contextual priors may have been convolved with the players' previous experience with regard to facing opponent's in similar scenarios within an actual performance setting. In other words, it may be that the players relied on information that would have been relevant in real-world settings (e.g., the distance between the marking defender and the attacker off the ball) to assess the chances that the opponent would dribble or pass the ball; however, as this information did not have any bearing for the outcome of the video-based task in this study, this reliance resulted in inferior response accuracy relative to if they had opted for the most likely direction, given the opponent's action tendencies, on each single trial. The fact that the players performed worse than what would have been expected if they had relied on the opponent's action tendencies alone, suggests that they did not act in an optimal Bayesian manner to solve the task. However, as discussed above, this may be explained by a discrepancy between information that would have been reliable in real-world scenarios and the information presented in the test task. That is, it is possible that the players weighed the information at hand in a manner that would have been probabilistically optimal in real-world settings, but that the probabilistic relationships of the test task did not fully reflect those of a real match.

In contrast to what we predicted, the use of priors did not engender increased levels of perceived cognitive load for experts or novices. These findings concur with those reported in previous studies with expert soccer players (Broadbent et al., 2018) and cricket batters (Runswick et al., 2018a; Runswick et al., 2017). However, it is possible that the retrospective reports collected in our study reflected the players' perception of task difficulty rather than cognitive load and, furthermore, that the reports did not accurately capture the fluctuation in demands over the course of a trial (see Antonenko et al., 2010). These potential limitations, along with the notion that conditional integration of a priori probabilistic rules and top-down attentional control bring about increases in cognitive load (De Neys et al., 2002; Kaplan & Berman, 2010; Waldmann & Hagmayer, 2001) suggests that researchers should explore this topic further; for example, by using concurrent neuroscientific techniques, such as EEG (Antonenko et al., 2010). Due to the limited capacity of working memory (Paas et al., 2003), an increased understanding of this phenomenon may have practical implications for performance under cognitively demanding conditions; for example, in the presence of a secondary task (Abernethy, Maxwell, Masters, van der Kamp, & Jackson, 2007).

In summary, the novel findings of this study suggest that the explicit provision of contextual priors biases anticipatory judgements and shapes the underlying perceptual and cognitive strategies employed by athletes. As prescribed by Bayesian models for probabilistic inference, the impact of explicit contextual priors seems to alter as a function of the relative reliability associated with the available sources of information (Körding, 2007). The temporal effects, together with the expertise effects reported in this study, suggests that these reliabilities are governed by the temporal relevance of the information at hand as well as the individual's ability to infer this relevance. It appears that experts integrate contextual priors with visual information more effectively than novices. This effect was highlighted in the data by the shifts in overt visual attention according to prevailing contextual information and updating of anticipatory judgements as new confirmatory or conflicting information emerged. In keeping with Bayesian theory, this resulted in a more reliable joint estimate of the to-be-anticipated action and enabled experts to anticipate with greater efficiency than their novice counterparts. These findings extend the utility of a Bayesian framework when examining anticipatory behaviours in sport and may be used to inform adequate instructional approaches for practitioners at different skill levels.

Chapter 4: The Effect of Informational Reliability on Experts' Integration of Explicit Contextual Priors and Visual Information

4.1 Abstract

According to Bayesian models for probabilistic inference, people make predictive judgments about the world based on the relative uncertainties associated with the information at hand; namely, more weight is placed upon sources that provide more reliable information. However, our understanding of how this process occurs to facilitate action anticipation in sport is limited. A soccer-specific video simulation task was used to examine the strategies employed by experts when integrating explicit contextual priors and evolving visual information conveying various levels of reliability during action anticipation. Expert players had to predict the direction of an oncoming opponent's imminent actions under conditions where the reliabilities of explicit contextual priors (i.e., the opponent's action tendencies) and pertinent visual information (i.e., opponent kinematics) were manipulated. Results showed that the players became less reliant on explicit contextual priors as the reliability of kinematic information increased. When kinematic information was more reliable, players were more dependent on explicit contextual priors of high, rather than low, reliability. Our findings suggest that the players employed reliability-based strategies when integrating contextual priors and visual information during action anticipation. That is, they relied more upon sources of relatively higher reliability, and vice versa.

4.2. Introduction

Chapter 3 demonstrated the impact of explicit contextual priors on expert soccer players' anticipatory judgements of opponents' forthcoming actions. In line with previous suggestions (Loffing & Cañal-Bruland, 2017), the findings reported in Chapter 3 imply that the players employed reliability-based strategies when integrating contextual priors with emerging visual information during task performance. Specifically, the impact of explicit contextual priors decreased as the reliability of the opponent's kinematic information increased (see Vilares & Körding, 2011). However, in Chapter 3, the response times of players' judgements were not standardised across trials or participants and, as such, the reliability of the progressively unfolding kinematic information prior to the players' judgements was not controlled for. Furthermore, the strength of the opponent's action tendencies was kept constant, so the reliability of the contextual priors was merely altered in relative terms (i.e., the comparative reliability of contextual priors decreased as the opponent's kinematics became more reliable), while a comparison between the impact of contextual priors of different levels of absolute reliability was not possible. The study presented in the current chapter seek to address these issues in order to gain further insight into expert soccer players' weighing of explicit contextual priors and evolving visual information during action anticipation.

According to Bayesian theory, people strive to reduce the uncertainty in their anticipatory judgements by integrating contextual priors with current visual information in a probabilistic manner. This process implies that the impact of contextual priors is modulated by the reliability of the visual environment (Vilares & Körding, 2011). Using a diverse body of tasks such as arm-reaching (Brouwer & Knill, 2009), pointing (Tassinari et al., 2006), and event-timing (Miyazaki et al., 2005) tasks, researchers have demonstrated that the extent to which we rely on prior and current information is contingent upon the comparative reliability associated with the information at hand. Furthermore, in the forensic domain, Dror and colleagues (2005) demonstrated that people were more likely to make 'match' judgements between fingerprints, after they had been explicitly primed with contextual information, such as background stories and photos from the crime scene. Importantly, this biasing effect of contextual priors was only found for ambiguous fingerprints (i.e., fingerprints that conveyed low-reliability visual information) and not for clear fingerprints (i.e., fingerprints that conveyed high-reliability visual information).

In sport, researchers have employed the temporal occlusion paradigm to alter the availability of visual information when examining athletes' ability to anticipate opponents' forthcoming actions (Farrow et al., 2005). The temporal occlusion paradigm has also been used to examine the extent to which athletes' reliance upon contextual priors is modulated by the reliability of evolving visual information. In a study by Runswick and colleagues (2018b), cricket batters had to predict the location of a bowler's forthcoming deliveries. The video stimuli were occluded at various time points relative to ball release which required the batters to respond under conditions in which the bowler's kinematics and the ball offered various levels of reliability with regard to the location of the delivery. When the stimuli were occluded during the early stages of the bowler's run-up (i.e., in the presence of low-reliability kinematics and ball flight information), contextual priors in the form of the bowler's action tendencies, game state, and field setting were the dominant sources of information on which expert batters relied. When the stimuli were occluded closer to the point of ball release (i.e., in the presence of high-reliability kinematics and ball flight information), expert batters predominantly used visual information relating to the bowler's kinematics and the ball flight to inform their judgements.

Similar findings were reported in a study by Gray and Cañal-Bruland (2018). The authors used a virtual baseball batting task to examine the extent to which the impact of explicit contextual priors pertaining a pitcher's action tendencies was modulated by the reliability of pertinent visual information (the ball was occluded 50, 100, and 150 ms after the pitcher had released the ball). It was demonstrated that the impact of the contextual priors on batting performance decreased as the availability of ball flight information increased (i.e., as the ball flight became more reliable). In this study, the authors not only altered the reliability of evolving visual information, but also the reliability of contextual priors (e.g., the chance that the pitcher would throw a fastball was either 50%, 65%, or 80%). It was shown that the beneficial effects of explicit contextual priors on performance increased, as the strength of the pitcher's action tendencies increased.

In keeping with Bayesian theory, these findings suggest that athletes' integration of contextual priors is moderated both by the reliability of current visual information *and* the reliability of the priors themselves. However, in Chapter 3, it was found that the effects of contextual priors seem to be modulated by the congruency between the priors and evolving visual information (see also Loffing et al., 2015; Mann et al., 2014). Thus, it remains unclear whether the comparative performance effects of contextual priors pertaining to subtle and strong action tendencies reported by Gray and Cañal-Bruland (2018) were driven by the strength of the pitcher's action tendencies, or merely by the amount of trials in which the pitcher performed the most likely pitch, given his action tendencies. In other words, it is possible that the extent to which the batters anticipated the 'most likely pitch' did not differ across conditions of subtle and strong action tendencies, but the benefits of doing so were greater in the latter condition.

The aim of the current study is to further explore the extent to which the effects of contextual priors and evolving visual information during action anticipation are modulated by the reliabilities of the different sources of information. This study adopted the same anticipation task employed in Chapter 3. However, to standardise the reliability of visual information prior to each response, a temporal occlusion paradigm was employed: expert soccer players were required to predict the direction of the opponent's final action in the presence of kinematic information of low (occlusion halfway through each trial) and high (occlusion at the end of each trial) reliability. Furthermore, the strength of the opponent's action tendencies was altered, such that the players performed the task under conditions with contextual priors of low (dribble = 60%; pass = 40%) and high (dribble = 80%; pass = 20%) reliability.

Based on the findings reported in Chapter 3, it was hypothesised that the explicit provision of contextual priors would bias players' anticipatory judgements toward the most likely direction, given the opponent's action tendencies. In line with Bayesian models for probabilistic inference, it was predicted that these effects would be modulated by the reliability of the information at hand (see Vilares & Körding, 2011). It was assumed that this would manifest itself in the fact that, in the presence of low-reliability kinematic information, explicit contextual priors of both low- and high-reliability would increase response accuracy on congruent trials. It was also predicted that, for incongruent trials, the biasing effects of both high and low-reliability contextual priors would be expressed by decreased response accuracy, when kinematic information was associated with low reliability. In keeping with Bayesian theory, it was hypothesised that these biasing effects would be more pronounced when the priors were associated with high, rather than low, reliability. Furthermore, it was predicted that the biasing effects of explicit contextual priors would decrease as the reliability of the opponent's kinematic information increased. Hence, only highly reliable explicit contextual priors would bias participants' judgments (i.e., they would be beneficial on congruent trials and detrimental on incongruent trials) when highly reliable kinematic information was available.

4.3 Methods

4.3.1 Participants. A total sample of 15 expert (M_{age} = 25 years, *SD* = 4) female soccer players participated. A spreadsheet for estimating sample size for magnitude-based inferences (Hopkins, 2006) was used to calculate the number of participants needed to find a clear effect (i.e., chances of the true effect to be substantially positive and negative < 5%; Batterham & Hopkins, 2006) for our performance measure (response accuracy). The data from Chapter 3 were used to calculate the minimum required sample size (Hopkins et al., 2009). On average, the players had 14 years' (*SD* = 3) competitive experience in soccer and took part in 5 hours (*SD* = 2) of practice or match play per week. The study was approved by the College of Health and Life Sciences Research Ethics Committee (see Appendix 3) and conformed to the recommendations of the Declaration of Helsinki. Written informed consent was obtained from all participants.

4.3.2 Test stimuli and task. The test stimuli were represented by the same video-based soccer scenarios that were used in Chapter 3. However, halfway through each trial (after ~2.5 s), the sequence was occluded, and a black screen was displayed. Upon occlusion, the task for the participant was to predict the direction (left or right) of the opponent's final action. Prior to this occlusion point, available kinematic information was considered to be associated with high uncertainty with regard to the direction of the final action. Therefore, these responses reflected the participant's anticipatory judgment under *low-reliability* kinematic information (see Figure 4.1a). Responses were recorded via two handheld response devices; one for 'left' and one for 'right' responses, held by the left and right hand, respectively. Immediately after their response, the second half of the trial started to unfold on the screen from the point of occlusion. The second half of the trial was occluded 120-240 ms prior to the last foot-ball contact prior to the opponent's final action. Once the footage had occluded, the participant had to make a second prediction about the direction of the final action; the same response devices were used and the participant could either stick to the direction initially predicted or change their decision. At this point, the kinematic cues revealed by the opponent were considered to be associated with low uncertainty. Therefore, these responses reflected the participant's anticipatory judgment under *high-reliability* kinematic information (see Figure 4.1b). Different occlusion points were chosen for when the opponent passed (−120 ms) and dribbled (−240 ms) the ball, as the findings in Chapter 3 suggested that pertinent kinematic cues were revealed earlier in dribbling actions than they were in passing actions. After their response at the second occlusion point, feedback with regard to their final response accuracy was displayed on-screen. At each occlusion point, the black screen was shown for a maximum of five seconds, and the participant was instructed to respond quickly and accurately. If the participant responded after the occlusion screen, then that response was counted as incorrect. The test stimuli were projected onto a 4.1 x 2.3 m projection screen (AV Stumpfl, Wallern, Austria) using an NEC PE401H projector (NEC, Tokyo, Japan). The participant was positioned 4 m in front of the screen at the start of each trial, but they were free to move as they wished during task performance, in order to maximise the real-world representativeness of the task. As players in a soccer match are normally aware of the position of the ball and other players, each half of the trial started with a frozen frame for one second to allow the participant to detect this information (cf. Roca et al., 2011).

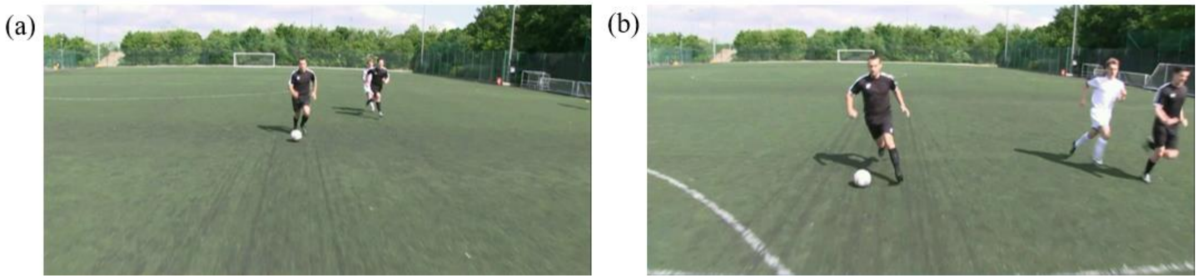

Figure 4.1. Test Stimuli. The figure illustrates the final frame before the first (a) and second (b) occlusion point of the trial.

Note: In this example, the direction of the final action was ‘left’ (i.e., the opponent dribbled the ball).

4.3.3 Procedure. Prior to testing, the participant was given an overview of the experimental protocol and was presented with six familiarisation trials to become accustomed to the experimental setup and the response requirements. After the familiarisation trials, the participant performed three blocks of ten test trials under two conditions which differed with regard to the opponent’s action tendencies. In one condition, the opponent exhibited only subtle action tendencies: he dribbled the ball in 60% of the trials and passed it to his teammate in the remaining 40%. Responses in this condition reflected the participant’s anticipatory judgment under *low-reliability* contextual priors. In the other condition, the opponent exhibited strong action tendencies: he dribbled the ball in 80% of the trials and passed it to his teammate only 20% of the time. Responses in this condition reflected the participant’s anticipatory judgment under *high-reliability* contextual priors. The participant performed these two conditions both with and without explicit provision of contextual priors. When contextual priors were explicitly provided, the opponent’s action tendencies were announced verbally and on-screen prior to each block (note: the opponent’s action tendencies also applied to the conditions where contextual priors were not explicitly provided).

In summary, the participant was required to predict the direction of the oncoming opponent’s final action under four conditions with varied informational uncertainty (see Figure 4.2). Namely, when both kinematic information and contextual priors were low in reliability ($KI^{Low}CP^{Low}$); when kinematic information and contextual priors were high and low in their reliability, respectively ($KI^{High}CP^{Low}$); when kinematic information and contextual priors were low and high in their reliability, respectively ($KI^{Low}CP^{High}$); and when both kinematic information and contextual priors were high in reliability ($KI^{High}CP^{High}$). The participant performed the task under these conditions, both with and without explicit provision of contextual priors pertaining to the opponent's action tendencies. In total, the participant performed 120 test trials and the entire session was completed within 90 minutes.

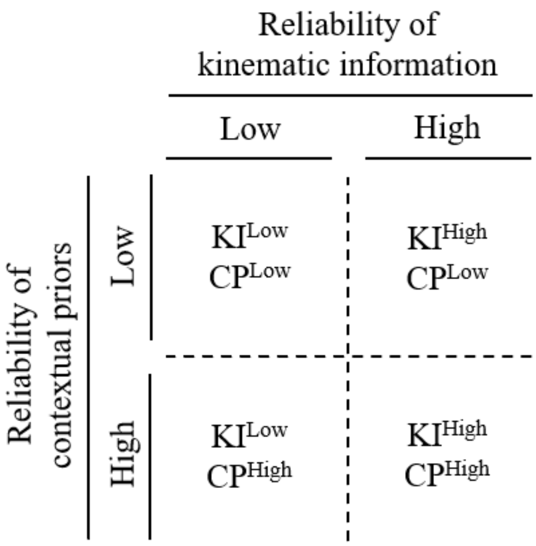

Figure 4.2. Experimental Conditions. The participant predicted the direction of the opponent's final action under four conditions that varied in the reliability of kinematic information and contextual priors.

Note: the task was completed under these conditions, both with and without explicit provision of contextual priors.

4.3.4 Data analysis. The impact of the explicit provision of contextual priors was evaluated within each condition. Specifically, a comparison was made between when contextual priors were explicitly provided and when they were not, in the four conditions. To assess the extent to which the effect of explicit contextual priors was moderated by the reliability of the priors, substantial effects of the same sign (i.e., *increase* or *decrease*) revealed under conditions with low- and high-reliability contextual priors were compared (i.e., $KI^{Low}CP^{Low}$ versus $KI^{Low}CP^{High}$; $KI^{High}CP^{Low}$ versus $KI^{High}CP^{High}$. The extent to which the effect of explicit contextual priors was moderated by the reliability of kinematic information was assessed by comparing substantial effects of the same sign revealed under conditions with low- and high-reliability kinematic information (i.e., $KI^{Low}CP^{Low}$ versus $KI^{High}CP^{Low}$; $KI^{Low}CP^{High}$ versus $KI^{High}CP^{High}$). As it was predicted that response accuracy would depend upon the congruency between the contextual priors and the opponent's final action, both combined and separate analyses of congruent and incongruent trials were carried out.

4.3.4.1 Statistical analysis. Descriptive statistics are reported as means and *SD*s. Magnitudes of observed effects along with their 90% CIs are reported as standardised (d) and unstandardised units. Effects were standardised by dividing the mean effect by the combined *SD* (Cumming, 2012). The following scale, suggested by Cohen (1988) was used to interpret standardised observed effects: $0.2 > |d|$, trivial; $0.2 \leq |d| < 0.5$, small; $0.5 \leq |d| < 0.8$, moderate; $0.8 \leq |d|$, large. Cohen's standardised unit for the smallest substantial effect (0.2) was used as a threshold value when estimating the uncertainties in true effects. Quantitative chances were converted to qualitative descriptors, using the following scale: 25-75%, possible; 75-95%, likely; 95-99.5%, very likely (Hopkins, 2002). If the lower and upper bounds of the confidence interval exceeded the thresholds for the smallest substantial negative and positive effect, respectively, then the effect was deemed unclear. Clear effects were reported as the magnitude of the observed value and were evaluated probabilistically as described above (Batterham & Hopkins, 2006).

4.4 Results

Figure 4.3 presents the response accuracy in each condition, both in the absence and present of explicitly provided contextual priors. The explicit provision of contextual priors increased the response accuracy in $KI^{Low}CP^{Low}$, $KI^{Low}CP^{High}$, and $KI^{High}CP^{High}$, both for the overall response accuracy ($d = 0.39 \pm 0.61$, $d = 0.59 \pm 0.42$, and $d = 0.70 \pm 0.52$, respectively) and when accuracy on congruent trials was analysed separately ($d = 0.48 \pm 0.40$, $d = 0.54 \pm 0.38$, and $d = 0.87 \pm 0.52$, respectively). No clear effects of explicit contextual priors were yielded in $KI^{High}CP^{Low}$, neither for overall accuracy nor when congruent trials were analysed separately. On incongruent trials, the explicit provision of contextual priors produced a decrease in response accuracy in $KI^{Low}CP^{Low}$ ($d = 0.29 \pm 0.40$) and $KI^{Low}CP^{High}$ ($d = 0.26 \pm 0.38$), but no clear effects were found in $KI^{High}CP^{Low}$ or $KI^{High}CP^{High}$. Unstandardised effects of the explicit provision of contextual priors on response accuracy in each experimental condition are presented in Table 4.1.

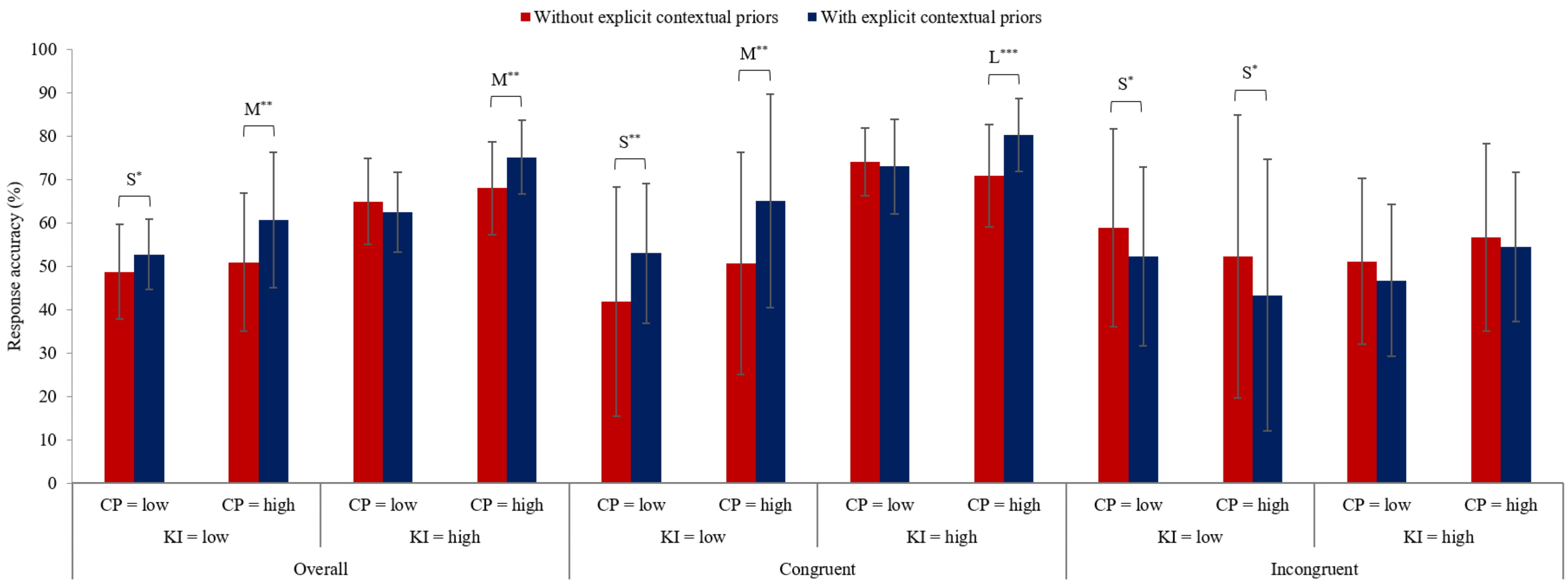

Figure 4.3. Response Accuracy. Means and *SD*s for response accuracy, as well as inferences of observed and true effects of explicit contextual priors in each condition. Inference of observed effects: $0.2 \leq |d| < 0.5$, small (S); $0.5 \leq |d| < 0.8$, moderate (M); $0.8 < |d|$, large (L). Inference of uncertainty in true effects: * possibly (25-75%); ** likely (75-95%); *** very likely (95-99.5%).

Note: KI = low, kinematic information of low reliability; KI = high, kinematic information of high reliability; CP = low, contextual priors of low reliability; CP = high, contextual priors of high reliability.

To explore the extent to which the effects of explicit contextual priors were moderated by their reliability, the effects obtained in $KI^{Low}CP^{Low}$ were compared to those in $KI^{Low}CP^{High}$. However, these comparisons did not yield any clear differences, neither for overall accuracy nor when the accuracy scores on congruent and incongruent trials were analysed separately. Furthermore, the effects revealed in $KI^{Low}CP^{High}$ were compared to the effects obtained in $KI^{High}CP^{High}$, in order to determine to what extent the effects of explicit contextual priors were moderated by the reliability of kinematic information. On congruent trials, these analyses yielded that the effect was greater in $KI^{Low}CP^{High}$ than in $KI^{High}CP^{High}$ (d = 0.23 ±0.30), but no substantial difference was revealed between the two informational conditions for overall response accuracy (d = 0.17 ±0.33).

Table 4.1

Unstandardised Effects (M ±90% CI) of Explicit Contextual Priors on Response Accuracy (%) under the Four Experimental Conditions

	KI = low		KI = high	
	CP = low	CP = high	CP = low	CP = high
Overall	4.0 ± 6.1	9.8 ± 7.0	−2.4 ± 6.3	7.1 ± 5.3
Congruent	11.1 ± 9.4	14.4 ± 12.2	−1.1 ± 5.0	9.4 ± 5.7
Incongruent	−6.7 ± 9.2	−8.9 ± 12.8	−4.4 ± 9.6	−2.2 ± 9.9

Note: KI = low, kinematic information of low reliability; KI = high, kinematic information of high reliability; CP = low, contextual priors of low reliability; CP = high, contextual priors of high reliability.

4.5 Discussion

This study examined the extent to which the effects of contextual priors and visual information during action anticipation are modulated by the reliabilities associated with the different sources of information at hand. Specifically, the accuracy of expert soccer players' anticipatory judgments of an oncoming opponent's imminent actions was assessed. The players had to predict the direction of the opponent's forthcoming actions, both with and without explicit provision of contextual priors pertaining to the opponent's action tendencies. Furthermore, the task was performed under conditions where kinematic information and contextual priors were either low or high in their reliability.

In line with the predictions, when the kinematic information was associated with low reliability (i.e., after the first half of the trial), explicit contextual priors of both low (i.e., subtle action tendencies: dribble = 60%; pass = 40%) and high (i.e., strong action tendencies: dribble = 80%; pass = 20%) reliability enhanced response accuracy on congruent trials, whereas the opposite effect was found for incongruent trials. These findings suggest that, in the absence of reliable kinematic information, the explicit provision of contextual priors biased expert soccer players' anticipatory judgments toward the most likely outcome, given the contextual priors. These findings align with the interpretations made in Chapter 3 with regard to the biasing effects explicit contextual priors had on visual dwell time and online anticipation accuracy; namely, that the expert players used the direction change of the attacker off the ball, which occurred over the first trial half, to inform their anticipatory judgements before reliable kinematic information emerged. It is worth noting that, in contrast to my predictions, no clear differences were found when the effects of explicit contextual priors pertaining to subtle and strong action tendencies were compared – neither on congruent nor incongruent trials. These findings imply that the relative uncertainty levels associated with contextual priors of low and high reliability may not have been relevant in the absence of competing visual information. In other words, the reliability associated with the information about the opponent's action tendencies – regardless of whether the action tendencies were subtle or strong – may have been considered as high, relative to the reliability conveyed by the kinematic information available halfway through the trial.

As predicted, the biasing effects of the explicit provision of contextual priors decreased as the reliability of the opponent's kinematic information increased. This was expressed by the fact that the beneficial effect of low-reliability explicit contextual priors on congruent trials, that was revealed after the first half of the trial, was not found after the second trial half. Furthermore, while high-reliability contextual priors had a beneficial impact on congruent trials after both the first and the second trial half, the effect was greater after the first half. However, it is worth noting that this effect may have been influenced by the lower accuracy score obtained without explicit priors after the first half of the trial and, as such, there was greater room for improvement, compared to after the second trial half. It is also notable that, even if the increase in response accuracy was greater in the presence of kinematic information of low, rather than high, reliability in unstandardised terms (14.4% vs. 9.4%), the standardiser (i.e., the combined between-participant SD) was greater when the reliability of kinematic information was low (SD = 25.07), rather than high (SD = 10.23); this resulted in the fact that a moderate standardised effect was obtained in the former condition, whereas a large standardised effect was revealed in the latter. The report of standardised effect sizes is preferable when the threshold value for a given effect size cannot accurately be expressed in unstandardised units, which today is the case for most laboratory-based studies in sport psychology (Hopkins et al., 2009). Furthermore, the report of standardised effect sizes generally allows for a more intuitive comparison of effects across tasks and studies than the report of unstandardised effects does (Morris & Fritz, 2013). However, when comparing magnitudes of effects between groups or conditions that significantly differ in their interindividual variability, the comparison of unstandardised effects generates a more accurate estimate, as they are less prone to interindividual homogeneity (Baguley, 2009). The weighted integration of information has previously been demonstrated in simple and generic sensorimotor tasks (e.g., Brouwer & Knill, 2009; Miyazaki et al., 2005; Tassinari et al., 2006), in applied settings outside the sporting domain (Dror et al., 2005), as well as in interceptive batting sports (Gray & Cañal-Bruland, 2018; Runswick et al., 2018b). The findings from these studies align with the Bayesian notion that the impact of contextual priors is moderated by the reliability of current visual information (Vilares & Körding, 2011). The current study provides further support for this notion and lends further support to the utility of reliability-based models when trying to elucidate the integration of contextual priors and visual information during action anticipation in sport.

The interaction of explicit contextual priors and kinematic information was also evident when comparing the impact of low- and high-reliability priors after the second half of the trials – that is, in the presence kinematic information of high reliability. In line with the predictions, only highly reliable explicit contextual priors, and not lower reliable priors, had a beneficial effect on response accuracy under these conditions. In keeping with the study by Gray & Cañal-Bruland (2018), this finding suggests that the beneficial effects of explicitly provided contextual priors pertaining to an opponent's action tendencies increases as the strength of the opponent's action tendencies increases. However, in contrast to the study by Gray & Cañal-Bruland (2018), the current study applied both combined and separate analyses of congruent and incongruent trials. Such analyses are important in order to determine if the increased beneficial overall performance effects are driven by increased reliance upon the opponent's action tendencies, or merely by the fact the relying on this information is more beneficial due the higher occurrence of the most likely action, given the opponent's action tendencies. Thus, the current study provides novel evidence for the fact that the increased beneficial performance effect obtained with contextual priors of comparatively higher reliability was driven by an increased reliance upon the priors, which was expressed by an increased beneficial effect on congruent trials. The fact that this interaction effect was not reflected in the response data obtained after the first half of the trial suggests that the reliance on explicit contextual priors is modulated not only by the reliability of the priors themselves, but also by the reliability of evolving kinematic information. That is, the relative uncertainty levels associated with contextual priors of low and high reliability are more relevant in the presence of competing kinematic information.

The suppressing effects of increased kinematic reliability on the impact of explicit contextual priors were also manifested in the players' responses on incongruent trials after the second half of the trial. As predicted, the explicit provision of low-reliability priors did not have any substantial effect on incongruent trials in the presence of high-reliability kinematic information. However, in contrast to my predictions, I did not find any substantial effect of the explicit provision of high-reliability contextual priors after the second half of the trial either. This means that the detrimental effects of the explicit provision of both low- and high-reliability contextual priors, which were obtained under conditions with low-reliability kinematic information, were washed out in the presence of highly reliable kinematic information. In line with the interpretations made in Chapter 3, these findings imply that the players were able to update the judgments they made after the first half of the trial according to the opponent's action tendencies, with conflicting kinematic information emerging over the second half of the trial. However, the study in Chapter 3 did not standardise the response times across trials or participants, and as such did not control for the uncertainty of visual information available prior to each response. In comparison, the results from the temporal occlusion paradigm adopted in the current study provides more valid support for that the players employed reliability-based integration strategies to combine contextual priors and evolving visual information during task performance.

In summary, the novel findings in this study provide valuable insight with regard to how experts integrate explicit contextual priors and kinematic information during action anticipation in soccer. In keeping with Bayesian theory (see Vilares & Körding, 2011), I demonstrated that the biasing effects of explicitly provided contextual priors is contingent upon both the reliability of the priors themselves *and* the reliability conveyed by available kinematic information. Namely, more weight is given to sources of information associated with relatively lower uncertainty, and vice versa. This insight makes a significant contribution to the development of an overarching theoretical framework that can predict anticipatory behaviour under complex and dynamic performance conditions (Cañal-Bruland & Mann, 2015).

Chapter 5: The Impact of Task Load on Experts' Integration of Explicit Contextual Priors and Visual Information

5.1. Abstract

Athletes combine contextual priors and current visual information to inform their judgements and processing strategies employed during action anticipation. However, the cognitive load imposed by this process of integration, and the extent to which it is affected by increased task load, need to be further examined. In the current study, EEG data and retrospective ratings of cognitive load were collected from expert soccer players as they attempted to integrate contextual priors with visual information during an action anticipation task. Players were required to predict the action of an oncoming opponent, with and without explicit contextual priors, under two different task loads. Continuous EEG, retrospective ratings, and performance data were compared across all conditions. The EEG measures revealed that cognitive load increased when contextual priors were explicitly provided, whereas self-report data suggested a decrease in cognitive load. The provision of explicit contextual priors enhanced anticipation under low task load, but this effect was diminished under high task load. The findings have ramifications for the assessment of cognitive load during task performance and provide novel insight into the processing demands associated with the use of contextual priors during action anticipation. Furthermore, practical implications relating to the provision of explicit contextual priors under cognitively demanding conditions are considered.

5.2. Introduction

It is believed that athletes combine contextual priors and visual information to inform their judgements during action anticipation (Cañal-Bruland & Mann, 2015). Chapter 3 demonstrated that expert, but not novice, soccer players used explicitly provided contextual priors to guide their acquisition of visual information and to inform their online anticipatory judgements of an oncoming opponent's next move. The findings suggested that, as the opponent's execution of the to-be-anticipated action drew nearer, the players integrated unfolding kinematic information to inform their ultimate anticipatory judgement. The conditional integration of explicit contextual priors and visual information was further supported by the findings in Chapter 4. It is proposed that the effort of this integration process and the use of top-down attentional control driven by prior knowledge and beliefs, may detract from the limited resources of working memory (De Neys et al., 2002; Kaplan & Berman, 2010; Waldmann & Hagmayer, 2001). However, by means of retrospective self-reports, the study in Chapter 3 revealed that the integration of explicit contextual priors did not come with increased levels of perceived cognitive load. Due to several limitations associated with self-assessment of cognitive load, the current chapter will further explore the impact of explicit contextual priors on expert soccer players' cognitive load during action anticipation, but using more stringent methods. In the present study, a comparison is made between the use of retrospective self-reports and online psychophysiological measures for the examination of the cognitive load invested during task performance. Additionally, this study examines the extent to which the performance effects of explicit contextual priors are modulated by task load.

It has been suggested that athletes may integrate contextual priors and evolving visual information in accordance with Bayesian models for probabilistic inference (Loffing & Cañal-Bruland, 2017). Bayesian theory postulates that people make predictive judgements on the basis of causal probabilistic relationships known to the individual, where greater reliance is placed upon relationships that are associated with lower uncertainty (Vilares & Körding, 2011). Such reliability-based integration of information was demonstrated in Chapter 3 and 4, where contextual priors were shown to have a greater impact over the first half of a trial during which the opponent's kinematic information was less reliable, compared to during the second half of the trial. In Chapter 3, this temporal effect of contextual priors was manifested both in the allocation of overt visual attention and the anticipatory judgements exhibited by expert players. These findings align with those reported by Gray and Cañal-Bruland, (2018) and Runswick and colleagues (2018b) who assessed the relative impact of contextual priors over the course of a baseball- and cricket task, respectively.

Causal inference of information is deemed to involve semantic memory retrieval processes (De Neys et al., 2002), where increased conditionalization (e.g., integration of a priori probabilistic rules) leads to increases in processing demands (Waldmann & Hagmayer, 2001). Furthermore, top-down allocation of visual attention, which is driven by the individual's prior knowledge and beliefs (Corbetta & Shulman, 2002), is mediated by the central executive and is therefore deemed to impose greater processing demands than bottom-up, or stimulus-driven, attentional processes (Kaplan & Berman, 2010). Consequently, it could be assumed that using contextual priors to inform anticipatory processes and judgements would lead to increases in cognitive load. Since the capacity of working memory is limited (Paas et al., 2003), it would be interesting to explore the impact of varying task loads on the use of contextual priors. It may be that increased task load (e.g., a cognitively demanding secondary task) would detract from available cognitive resources which would, in turn, diminish the individual's ability to integrate contextual priors into their anticipatory judgements. An enhanced understanding of this phenomenon would have practical implications for a wide range of professional domains in which the practitioner must deal with considerable, not to mention highly variable, task loads (e.g., aviation [Gentili et al., 2014], military combat [Berka et al., 2007], and sport [Abernethy et al., 2007]).

In Chapter 3, however, the players did not report higher levels of cognitive load when contextual priors were explicitly provided, compared to when they were not. This finding concurs with those reported in other studies using the same retrospective self-report approach with expert soccer players (Broadbent et al., 2018) and cricket batters (Runswick et al., 2018b; Runswick et al., 2017). Furthermore, in these studies, the authors sought to elevate the cognitive demands of the task by increasing the levels of anxiety (Broadbent et al., 2018; Runswick et al., 2017; see also Eysenck, Derakshan, Santos, & Calvo, 2007) or by implementing a secondary backward-counting task (Runswick et al., 2018a). The findings from these studies contradict the assumption that the impact of contextual priors on performance and processing strategies would decline under more cognitively demanding performance conditions. However, the retrospective self-reports collected in these studies, including the study in Chapter 3, may not have been the most sensitive measure of cognitive load and do not provide an insight into potential temporal fluctuations in cognitive load induced by the contextual priors or, for that matter, the task manipulations during performance (Antonenko et al., 2010). Furthermore, it is possible that the self-report data reflected perceptions of task difficulty, rather than perceived levels of cognitive load. Although task difficulty is closely related to cognitive load, it is determined by the data available to solve the task, rather than the individual's cognitive resources. Thus, a task may be perceived as less difficult (e.g., in the presence of additional task-relevant information) but at the same time be more cognitively demanding (e.g., in order to process additional task-relevant information), and vice versa (see Westbrook & Braver, 2015). Conversely, psychophysiological measures of continuous cognitive load, such as electroencephalography (EEG) may provide a more sensitive measure, and enable objective evaluation, of cognitive load for specific durations during task performance (e.g., average load imposed over the first seconds of a trial; Antonenko et al., 2010).

The continuous EEG signal is composed of oscillations in various frequencies where power fluctuations within the theta (θ) and alpha (α) frequency bands (typically defined as 4-7 Hz and 8-13 Hz, respectively; Andreassi, 2007) are deemed to reflect changes in cognitive processing demands. Importantly, θ and α oscillations captures changes in cognitive processes, even when the individual is unaware of these changes or is unable to verbalise them (Antonenko et al., 2010). The cortical activity within the θ and α bands have been reported to partly represent different cognitive functions, to be predominant over different scalp regions, and to respond in opposite ways to increased cognitive load. Several researchers have demonstrated a positive correlation between frontal θ activity and the processing demands of vital cognitive functions, such as central executive attentional control, and encoding and retrieval of episodic information (see Hsieh & Ranganath, 2014; Sauseng et al., 2010). While the physiological function of the α rhythm is not fully clear, decreased activity in parietal α is deemed to reflect increased cognitive load (see Antonenko et al., 2010). One explanation as to why the relationship between α oscillations and alterations in cognitive load is unclear may be that the majority of researchers have applied a fixed, broad definition of the α rhythm (e.g., 8-13 Hz) for all participants, rather than using narrower bands (e.g., α_1: 8-10 Hz, α_2: 11-13 Hz) that are based on the Individual Alpha Frequency (IAF) for each participant. While α_1 is deemed to reflect non-task and non-stimulus specific demands, such as general arousal, activity within the higher α band is related to demands placed on task-specific processes, including stimulus inference and semantic memory retrieval (see Klimesch, 1999).

The current study focused on expert soccer players and compared spectral power estimates in frontal θ and parietal α_2 (EEG) with retrospective self-reports of cognitive load (RSME; Zijlstra, 1993) in order to gain novel insight into the cognitive load associated with processing of contextual priors during action anticipation in soccer. Furthermore, by adding a cognitively demanding secondary task (*n*-back), the impact of explicit contextual priors on anticipation under both low and high task load conditions was examined. It was predicted that the explicit provision of contextual priors would increase the cognitive load imposed on the players, due to increased causal inference of information and increased top-down allocation of visual attention (De Neys et al., 2002; Kaplan & Berman, 2010; Waldmann & Hagmayer, 2001). However, in line with the findings of the study in Chapter 3, it was hypothesised that this effect would only be manifested in the continuous EEG recordings and not in the players' self-assessed cognitive load. Based on the findings reported in Chapter 3, it was also predicted that the explicit provision of contextual priors would improve overall anticipation performance and that this beneficial effect would be driven by enhanced performance on congruent trials, whereas no substantial performance effect would be found on incongruent trials. However, due to a detraction of cognitive resources from the limited capacity of working memory (see Paas et al., 2003), it was expected that the performance effects of explicit contextual priors would diminish with increased task load.

5.3 Methods

5.3.1 Participants. A total of 17 expert male soccer players (M_{age} = 21 years, *SD* = 1) participated, which is comparable to the number participants in Chapter 3 and 4 in which clear within-participant performance effects of explicit contextual priors were obtained. This sample size is comparable to those employed in previous studies using EEG power spectral estimates to examine the cognitive processes employed during sport-task performance (e.g., Haufler, Spalding, Santa Maria, & Hatfield, 2000; Hillman, Apparies, Janelle, & Hatfield, 2000; Kerick et al., 2001). The players had a mean of 11 years' (*SD* = 2) competitive experience in soccer and took part in an average of 7 hours (*SD* = 3) of practice or match play per week. The study was approved by the College of Health and Life Sciences Research Ethics Committee (see Appendix 4) and conformed to the recommendations of the Declaration of Helsinki. Written informed consent was obtained from all participants.

5.3.2 Test stimuli and task. The test footage comprised 36 video clips simulating the same soccer sequences that were used in Chapter 3. The stimuli were projected at a size of 2.1 x 1.6 m onto a projection wall using an Optoma HD20 DLP projector (Optoma, New Taipei City, Taiwan). The participant was seated 3 m in front of the projection wall and tasked with predicting the direction (left or right) of the opponent's final action. Responses were recorded via two handheld response devices; one for 'left' and one for 'right' responses, held by the left and right hand, respectively. The participant was instructed to respond as soon as they were certain enough to carry out an action based on their prediction. Immediately after the participant's response, the sequence was occluded and feedback for response time and accuracy was displayed on-screen. If the participant responded 120 ms or more after the foot-ball contact of the attacker in possession's final action, then that trial was counted as incorrect.

5.3.3. Procedure. Prior to testing, the participant was given an overview of the experimental protocol and donned a portable EEG system (see details below). Thereafter, continuous EEG data were recorded over a pre-test period of 2 mins, during which the participant was encouraged to stay seated in a comfortable position with their eyes closed while avoiding any head or body movements. The participants then performed four familiarisation trials in order to become acquainted with the experimental setup and response requirements. The 36 test trials were then presented under three different conditions (i.e., 108 test trials in total), In both the *EXP* and EXP^{TL} conditions, contextual priors (i.e., information about the opponent's action tendencies; dribble = 67%, pass = 33%) were explicitly provided prior to each block, both verbally and on-screen. In order to increase the cognitive demands in $\mathrm{EXP}^{\mathrm{TL}}$, the task load was manipulated using a secondary *n*-back task. After four randomly selected trials within each block, the participant had to indicate the direction of the final action two trials previous. To maintain the participant's engagement with both tasks, they were instructed that the responses on the secondary task were equally important as those for the primary anticipation task. In the *CTRL* condition, no secondary task was performed, and no contextual priors were explicitly provided (note: the proportion of trials where the opponent dribbled [67%] and passed [33%] the ball was the same in all three conditions). The order in which conditions were presented was randomised and counterbalanced across participants. To eliminate the influence of trial-specific characteristics, the same 36 trials were presented in all three conditions. However, to avoid any potential familiarity effects across conditions, the trial order in each condition was randomised. At the beginning of each condition, participants performed five condition-specific familiarisation trials, after which the 36 test trials were presented in three blocks of 12 trials each.

Response accuracy and response time were recorded for each trial. Continuous EEG data were recorded for each condition, and the EEG trace was automatically tagged with event markers that indicated stimulus onset. The participant was encouraged to remain still and to avoid eye blinks, where possible, during the task. Upon completion of each condition, the participant was asked to state, using the RSME (Zijlstra, 1993), their perception of the level of cognitive load they had expended in order to perform the trials in the preceding condition. The entire test session was completed in 90 mins.

5.3.4 EEG recording and processing. The EEG data were recorded using a portable 'EEGo Sports' EEG system (ANT Neuro, Enschede, Netherlands) with 32 Ag/AgCl electrodes arranged according to the international 10-20 system (including left and right mastoids, CPz as reference and AFz as ground; Jasper, 1958). Impedances were kept below 10 kΩ, and the sampling rate was set to 500 Hz. A bandpass filter setting of 0.1–100 Hz and a 60-Hz notch filter was applied during the recording to avoid electrical interference and muscle artefacts.

The data were processed offline using Brainstorm (Tadel, Baillet, Mosher, Pantazis, & Leahy, 2011), which is freely downloadable under the GNU public license (http://neuroimage.usc.edu/brainstorm). The signal was re-referenced to linked mastoids and then submitted to a high-pass (0.5 Hz) and low-pass (30 Hz) filter to reduce low-frequency and high-frequency noise, respectively. Ocular artefacts were further identified and corrected using Independent Component Analysis (ICA) in line with the guidelines provided by Dickter and Kieffaber (2014). After the ICA procedure, the continuous data file was partitioned into single epochs of 2,300 ms. The conditions were epoched into 36 single trials beginning 200 ms after stimulus onset and ending 2,500 ms after stimulus onset. This time window was chosen based on the findings from Chapter 3 and 4 so as to include the stage of the trial during which the participants were predicted to be particularly reliant on contextual priors. The pre-test baseline period was epoched into 36 successive segments, to match the number of trials in the test conditions. Each trial was visually inspected for residual artefacts and contaminated trials were discarded from subsequent analyses. Decisions about rejecting individual epochs were made by an experimenter, who was blind as to the condition to which they belonged. Arbitrary amplitude thresholds for artefact rejection were not used (Meltzer, Negishi, Mayes, & Constable, 2007).

Contaminate-free segments from the pre-test baseline period and each condition (average = 32, minimum = 25, maximum = 36) were submitted to a Fast Fourier Transformation (FFT) to transform the time-course signal into power estimates for different wave frequencies. Power estimates were averaged across trials so that separate averages were obtained for the baseline period and each test condition. Average power estimates in the test conditions were then grouped into individualised θ and α_2 frequency bands. Individualised frequency bands were used, as fixed bands may blur specific relationships between cognitive performance and power measurements (Klimesch, 1999). The frequency-band borders were determined using the IAF for each participant as an anchor point. The IAF was determined by visual inspection of the average peak α frequency (i.e., the maximum power value within the α band) over the baseline period; θ = IAF − 6 Hz to IAF − 2.5 Hz, α_2 = IAF to IAF + 2.5 Hz (Pavlov & Kotchoubey, 2017). Spectral power estimates were obtained for frontal midline (Fz) and parietal midline (Pz) electrodes, as these are deemed to be the most sensitive sites when monitoring cognitive load via cortical activity within the θ and α frequency band, respectively (Scharinger, Soutschek, Schubert, & Gerjets, 2015). Prior to further analysis, all data were log-transformed to reduce bias arising from non-uniformity of error.

5.3.5 Data analysis. Our primary measure for cognitive load was defined by the spectral power ratio between frontal θ and parietal α_2 (Fz θ/Pz α_2), where amplified power ratio indicated an increase in cognitive load. The frontal θ to parietal α ratio has successfully been used to measure the overall cognitive load placed on WM during task performance (e.g., Fuentes et al., 2018; Holm et al., Müller, 2009; Jaquess et al., 2017; Postma & Schellekens, 2005) and is deemed to be more sensitive to changes in cognitive load than absolute spectral power (Holm et al., 2009). In the current study, we restricted our analyses to α_2, to avoid non-task and non-stimulus specific demands associated with lower α frequencies from violating the cognitive load index (Klimesch, 1999). In order to trace the mechanisms underpinning such changes, we also analysed the absolute spectral power in Fz θ and Pz α_2, separately.

Self-assessed levels of cognitive load were expressed as the RSME score reported for each condition (cf. Broadbent et al., 2018; Runswick et al., 2018a; Runswick et al., 2017). The scale ranges from 0 to 150 and contains nine descriptors; higher ratings indicate higher levels of perceived cognitive load (e.g., 2 = absolutely no effort; 58 = rather much effort; 113 = extreme effort).

Anticipation performance was expressed by the same anticipation efficiency score that was employed in Chapter 3. That is, the average response time was multiplied by the proportion of inaccurate responses which yielded an efficiency score for each condition, where a lower score indicated superior anticipation performance. Overall anticipation performance was defined by the anticipation efficiency score for congruent and incongruent trials, combined. As we predicted a congruence effect for anticipation performance, the efficiency score was also calculated for congruent and incongruent trials, separately.

The impact of explicit contextual priors on our dependent measures was assessed under conditions in which the explicit priors were provided in the company of low (EXP−CTRL) and high (EXP^{TL}−CTRL) task load. If substantial effects of the same sign (i.e., *increase* or *decrease*) were yielded for a certain dependent measure under both low and high task load, these effect magnitudes were compared.

5.3.5.1 Statistical analysis. Descriptive statistics are reported as means and *SD*s. Magnitudes of observed effects are reported as standardised (*d*) and unstandardised units and uncertainties in true effects as 90% CIs. The standardised effects were assessed by dividing the mean effect by the combined *SD* (Cumming, 2012). The following scale was used to interpret observed effects: $0.2 > |d|$, trivial; $0.2 \leq |d| < 0.5$, small; $0.8 \leq |d|$, large (Cohen, 1988). Cohen's standardised unit for the smallest substantial effect (0.2) was used as a threshold value when estimating the uncertainty in the true effect to have the same sign as the observed effect. The following scale was used to convert the quantitative chances to qualitative descriptors: 25-75%, possible; 75-95%, likely; 95-99.5%, very likely; > 99.5%, most likely (Hopkins, 2002). If the lower and upper bounds of the confidence interval exceeded the thresholds for the smallest substantial negative and positive effect, then the effect was deemed unclear. All other effects were reported as the magnitude of the observed value and were evaluated probabilistically as described above (Batterham & Hopkins, 2006).

5.4 Results

5.4.1 Cognitive load. As shown in Figure 5.1, our primary analysis of cognitive load showed that the Fz θ/Pz α_2 ratio was higher both in the EXP and the EXP^{TL}, compared to in CTRL ($d = 0.20 \pm 0.15$ and $d = 0.38 \pm 0.18$, respectively); the increase of the Fz θ/Pz α_2 ratio was greater in EXP^{TL} than in EXP ($d = 0.20 \pm 0.28$). Separate comparisons to the absolute power estimates in CTRL revealed that Fz θ power increased in EXP^{TL} ($d = 0.33 \pm 0.14$), but no substantial effect was yielded in EXP ($d = 0.01 \pm 0.12$). Compared to in CTRL, no substantial effect was found on the absolute power estimates in Pz α_2 in EXP ($d = 0.16 \pm 0.11$) or in EXP^{TL} ($d = 0.10 \pm 0.13$). The retrospective self-reports of cognitive load yielded a lower RSME score in EXP and a higher RSME score in EXP^{TL}, relative to in CTRL ($d = 0.29 \pm 0.31$ and $d = 0.85 \pm 0.36$, respectively; see Figure 5.1). Table 5.1 shows the unstandardised effects for Fz θ/Pz α_2 ratios and RSME scores in EXP and EXP^{TL}, compared to those in CTRL.

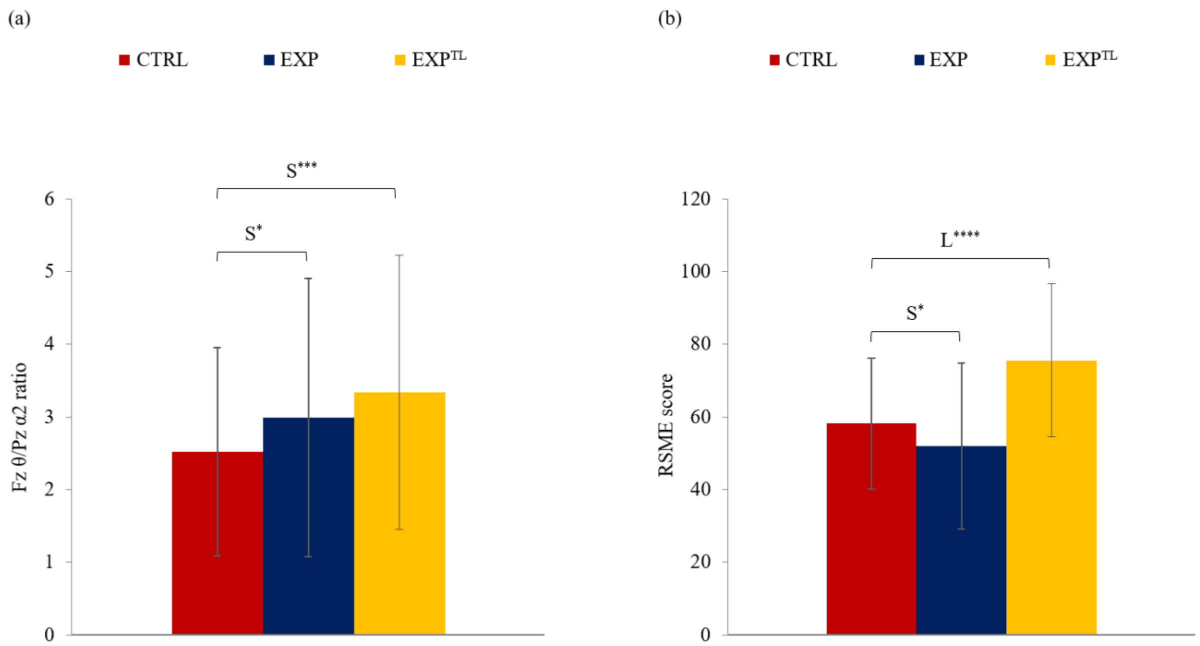

Figure 5.1. Cognitive Load. Means and *SD*s for (a) Fz θ/Pz α2 ratios and (b) RSME scores in each condition, as well as inferences of observed and true effects of explicit contextual priors under low (EXP−CTRL) and high (EXP^{TL}−CTRL) task load. Inference of observed effects: $0.2 \leq |d| < 0.5$, small (S); $0.8 < |d|$, large (L). Inference of uncertainty in true effects: * possibly (25-75%); *** very likely (95-99.5%); **** most likely (> 99.5%).

5.4.2. Anticipation efficiency. The descriptive statistics for the response times and the accuracy scores that were used to calculate the anticipation efficiency score in each condition are shown in Table 5.2. Figure 5.2 shows that, when compared to CTRL, the overall anticipation efficiency score was lower in EXP (d = 0.31 ±0.40) demonstrating enhanced performance, whereas no clear effect could be found in EXP^{TL}. Separate analyses revealed that performance improved on congruent trials as the anticipation efficiency score decreased (d = 0.36 ±0.37), whereas no clear effect was found on incongruent trials in EXP. No clear effect was found in EXP^{TL} on congruent trials, whereas performance was shown to worsen on incongruent trials as the anticipation efficiency score increased, compared to in CTRL (d = 0.30 ±0.37). Unstandardised effects for the anticipation efficiency scores in EXP and EXP^{TL}, relative to the score in CTRL, are presented in Table 5.1.

Table 5.2

Descriptive Statistics (M ± SD) for Response Time and Accuracy in Each Condition

	CTRL	EXP	EXP^{TL}
Response time (ms)			
Overall	4,488 ± 582	4,427 ± 600	4,450 ± 550
Congruent	4,522 ± 561	4,434 ± 609	4,473 ± 537
Incongruent	4,418 ± 853	4,414 ± 640	4,403 ± 731
Response accuracy (%)			
Overall	67 ± 12	70 ± 9	67 ± 11
Congruent	80 ± 15	85 ± 15	83 ± 15
Incongruent	43 ± 19	41 ± 11	36 ± 18

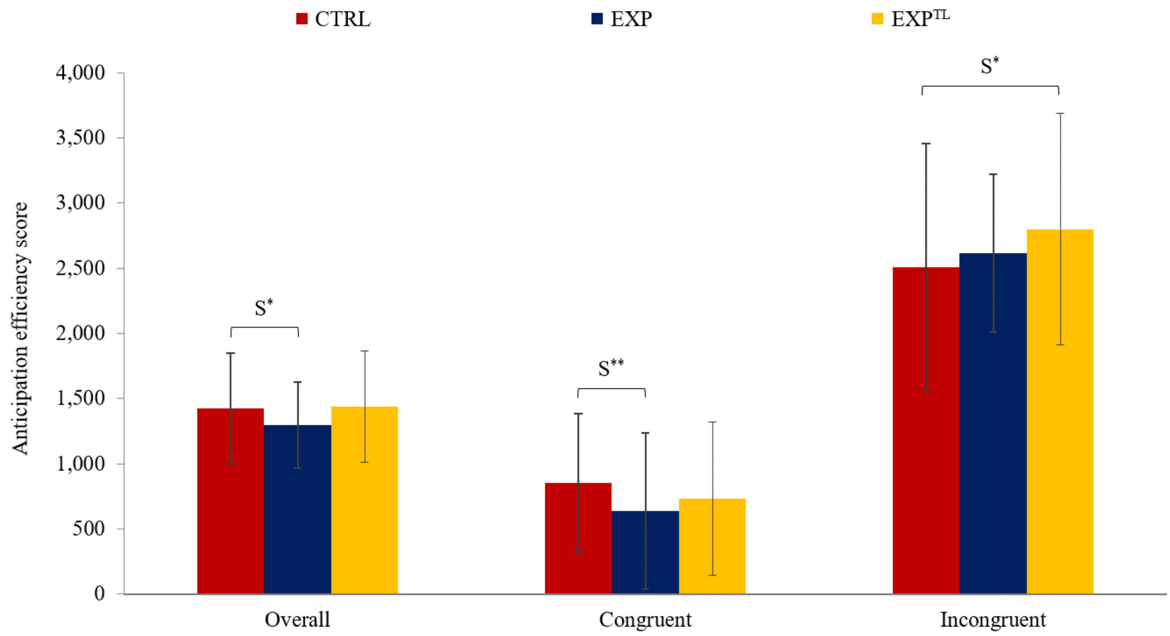

Figure 5.2. Anticipation Efficiency. Means and *SD*s for the anticipation efficiency score in each condition, as well as inferences of observed and true effects of explicit contextual priors under low (EXP−CTRL) and high (EXP^{TL}−CTRL) task load (note: lower efficiency scores indicate superior anticipatory efficiency). Inference of observed effects: $0.2 \leq |d| < 0.5$, small (S). Inference of uncertainty in true effects: * possibly (25-75%); ** likely (75-95%).

Table 5.1

Unstandardised Effects (M ±90% CI) of Explicit Contextual Priors on Cognitive Load and Anticipation Efficiency under Conditions of Low (EXP−CTRL) and High (EXP^{TL}−CTRL) Task Load

	Low task load	High task load
Cognitive load		
Fz θ/Pz α_2 ratio	0.5 ± 0.3	0.8 ± 0.4
RSME score	−6.2 ± 6.8	17.3 ± 7.3
Anticipation efficiency score		
Overall	−125.5 ± 159.4	13.9 ± 212.4
Congruent	−215.1 ± 219.7	−120.8 ± 242.7
Incongruent	102.9 ± 437.7	290.3 ± 359.1

Note: lower anticipation efficiency score indicates superior anticipation efficiency.

5.5 Discussion

In this study objective psychophysiological measures (EEG) and retrospective self-reports (RSME) were collected to gain an insight into the cognitive load associated with processing explicitly provided contextual priors during anticipation. Furthermore, the impact of explicit contextual priors on anticipation performance under conditions with low and high task load was examined.

In line with the predictions, it was found that the explicit provision of contextual priors amplified the spectral power ratio between frontal θ and parietal α_2, suggesting that the explicit contextual priors increased the cognitive load imposed on the players. In order to gain an insight into the demands placed on specific cognitive functions during task performance, I analysed the absolute spectral power in frontal θ and parietal α_2, separately. In contrast to what was predicted, the explicit provision of contextual priors was not accompanied with increased frontal θ activity. This finding was somewhat surprising, since the findings in Chapter 3 suggest that explicit contextual priors increased the time that expert soccer players spent looking at the players off the ball during the first half of the trial. This finding from the study in Chapter 3 implies that the explicit provision of contextual priors reinforced top-down control of visual attention, which is believed to correlate positively with the frontal θ spectral power, due to the processing demands placed on the central executive (Hsieh & Ranganath, 2014; Sauseng et al., 2010). An explanation for the trivial effect on frontal θ could be that, in contrast to the study in Chapter 3, the players in the current study had to remain seated and were instructed to avoid any type of body movements during performance. This design inevitably reduced the real-world representativeness of the action requirements of the task. Action fidelity with regard to the real-world requirements may be important for the task, in order to invoke representative gaze behaviour (Dicks et al., 2010). Thus, under the controlled laboratory conditions employed in this study, it is possible that the explicit provision of contextual priors did not promote top-down control of attention, as may be the case in more representative settings. In future, combination of EEG and eye-tracking data will enable researchers to further explore the relationship between attentional control and central executive processing demands during naturalistic anticipation tasks.

In contrast to what was predicted, no substantial effect on absolute parietal α_2 power was found. However, qualitative inferences pertaining to the true effect suggest it is possible that explicit contextual priors attenuate α_2 over the parietal region. This possible decrease in parietal α_2 indicates that the increased processing demands may be related to inference of task-specific information and semantic memory retrieval (Klimesch, 1999). These processes are linked to Bayesian strategies for information integration, where predictive judgements are made according to conditional inferences of certain *if-then* relationships known to the person (Clark, 2013; De Neys et al., 2002). In the present study, an informative *if-then* relationship was that of the positioning of the attacker off the ball. That is, *if* the attacker off the ball was positioned on the left-hand side of the attacker in possession, *then* it was more likely that the direction of the final action would be to the right, given the opponent's action tendencies. The findings reported in the previous chapters with regard to the expert players' allocation of visual attention (Chapter 3) and their judgement accuracy after the first trial half (Chapter 4), suggest that the explicit provision of contextual priors increased expert players' reliance on this relationship in order to inform their judgements. The possible decrease in parietal α_2 reported in the current study supports these findings and indicates that such propositional inference may bring about increases in cognitive load. However, it is worth noting that, while the qualitative inferences suggested a possible decrease in parietal α_2 power, the observed effect obtained in the current experiment was trivial. Therefore, the presence of an absolute power decrease in parietal α_2 should be inferred with some caution. Collectively, the separate analyses of frontal θ and parietal α_2 suggest that the increased frontal θ to parietal α_2 ratio may have been driven by decreased parietal α_2 power (reflecting inference of task-specific information and semantic memory retrieval), rather than increased frontal θ power (reflecting top-down control of visual attention). However, the absolute power changes in frontal θ and parietal α are deemed to be less sensitive than their power ratio, which is why the frontal θ to parietal α_2 ratio should be seen as a more accurate reflection of the cognitive load induced by the explicit provision of contextual priors (Holm et al., 2009).

In keeping with the findings reported in Chapter 3, it was predicted that the explicit provision of contextual priors would not have any substantial effect on the players' retrospective self-reports of cognitive load (see also Broadbent et al., 2018; Runswick et al., 2018a; Runswick et al., 2017). However, in contrast to this prediction, it was found that RSME scores decreased when contextual priors were explicitly provided, compared to when they were not. The decrease in self-assessed cognitive load conflicts with our objective psychophysiological measures of cognitive load. However, it has been suggested that retrospective ratings of cognitive load may not accurately capture the temporal fluctuations in cognitive load during task performance (Antonenko et al., 2010). It was suggested from Chapter 3 and 4 that the impact of contextual priors is greater over the first half of the trial, whereas players rely more on the opponent's kinematics in the later stages. Thus, it is possible that the temporal impact of explicit contextual priors on cognitive load was being overlooked when the players were asked to report the cognitive load invested in the task after each test condition. This explanation is supported by existing literature, which suggests that continuous EEG may capture changes in cognitive load of which the individual is unaware and unable to verbalise (Antonenko et al., 2010). However, this latter suggestion does not explain the *decrease* in self-reported cognitive load when contextual priors were explicitly provided, compared to when they were not. Given the increase in task-relevant information, along with enhanced overall performance in the condition with contextual priors, a potential alternative explanation could be that the self-reports actually reflected the players' perception of task difficulty, rather than the cognitive resources they invested in completing the task (see Westbrook & Braver, 2015). In other words, players found the anticipation task easier, and felt they did not have to put in as much effort in with the explicit provision of contextual priors, and thus gave a lower rating score on the subjective scale of cognitive load. In future, researchers should examine the validity of retrospective rating techniques, such as the RSME, and ensure that it is providing a measure of cognitive load and not just task difficulty.

Both EEG measures and self-reports suggest that cognitive load increased when the players had to perform the secondary *n*-back task in addition to the primary anticipation task. This finding suggests that the task manipulation was successful. It also supports the notion that the RSME may actually be measuring the participant's perception of task difficulty as the *n*-back task would provide an increase in both cognitive load and task difficulty. With regard to the EEG data, separate analysis of absolute spectral power revealed that the increased frontal θ to parietal α_2 ratio was driven by an increase in frontal θ, whereas no substantial effect was found on parietal α_2. The increased frontal θ activity suggests that greater encoding and retrieval of episodic information occurred, which aligns with findings from previous research in which the *n*-back paradigm has been used as a task load manipulation (Hsieh & Ranganath, 2014; Sauseng et al., 2010). Unlike the findings in the low-load condition, where a possible decrease in parietal α_2 was found, qualitative inferences suggest that it is unlikely that the explicit provision of contextual priors decrease parietal α_2 under high-load conditions. This finding implies that fewer cognitive resources were devoted to inference of task-specific information and semantic memory retrieval (Klimesch, 1999) which, in turn, suggests reduced assimilation of contextual priors under high-load conditions (De Neys et al., 2002; Waldmann & Hagmayer, 2001).

The diminished impact of explicitly provided contextual priors in the high-load condition was also evident in the effects on anticipation performance. In line with the predictions, explicit contextual priors had a beneficial effect on overall anticipation efficiency under low-load conditions. Separate analyses revealed that this effect was driven by improvements on congruent trials, whereas no clear effect was found for incongruent trials. These findings align with the findings reported in Chapter 3, suggesting that the expert soccer players integrated explicitly provided contextual priors with evolving kinematic information to inform their anticipatory judgements. However, as predicted, the beneficial performance effects obtained in the low-load condition diminished in the condition with high task load. Given the limited capacity of working memory (see Paas et al., 2003), it is reasonable to suggest that, when the players had to devote additional cognitive resources to deal with the secondary *n*-back task, fewer resources were available to process the contextual priors. The findings from the EEG data support this suggestion. This proposal may have practical implications for the effects of such information under performance conditions that vary in terms of task load (Abernethy et al., 2007; Berka et al., 2007; Gentili et al., 2014).

A detrimental performance effect of explicit contextual priors on incongruent trials was found in the high-load condition. This finding is comparable to that found for novice players under low-load conditions in Chapter 3 and suggests that increased task load decreases expert players' ability to update contextual priors with evolving kinematics to formulate their anticipatory judgements. While the EEG measurement of cognitive load was restricted to the first half of the trial in this study, the detrimental impact of explicit contextual priors on incongruent trials under high-load conditions suggests that the integration of kinematic information may also be associated with increased cognitive load. However, this proposal needs to be explored further; for example, by using fixed trial lengths (e.g., video occlusion prior to action execution) which will allow for standardised assessments of EEG activity in the latter stages of trials, where kinematic information from the attacker in possession becomes more informative.

In summary, the EEG measures provide novel evidence to suggest that the use of explicitly provided contextual priors may bring about increases in cognitive load during action anticipation. The contradictory findings from the self-reported cognitive load data have implications for the assessment of cognitive load. Namely, the findings add to the existing literature, suggesting that continuous EGG measures enable objective evaluation of cognitive load during task performance; something that may not be captured by retrospective self-reports (Antonenko et al., 2010). Furthermore, our performance data support findings from the study in Chapter 3, which suggest that expert soccer players use explicit contextual priors to improve anticipation performance. However, by using a combination of EEG and performance measures, this study provides novel evidence that the beneficial impact of a priori contextual information may decline with increased task load. This finding affords valuable insight with regard to the effectiveness of explicitly provided contextual priors under cognitively demanding performance conditions.

Chapter 6: The Impact of Judgement Utility on Experts' Integration of Explicit Contextual Priors and Visual Information

6.1 Abstract

It has been suggested that athletes may employ Bayesian reliability-based strategies to integrate contextual priors and visual information during action anticipation. However, the utility – a key component of Bayesian theory – associated with possible judgement has typically been overlooked in previous action anticipation research. In this study, the impact of judgement utility on expert soccer players' integration of explicit contextual priors and visual information as they predicted the direction of an oncoming opponent's imminent actions was examined. Anticipation performance and verbal reports of thoughts from players were compared across three conditions. In two of the conditions, contextual priors pertaining to the opponent's action tendencies were explicitly provided. In one of those conditions, the players received instructions that created imbalance in the utility associated with the possible judgements (left = high utility; right = low utility). In the third condition, no contextual priors or additional instructions were provided. It was found that explicit contextual priors changed the players' processing priorities and biased their anticipatory judgments in accordance with the opponent's action tendencies. However, in keeping with Bayesian theory, imbalance in judgement utility supressed these effects, and the players became more inclined to opt for the outcome with the higher utility.

6.2 Introduction

A growing body of research has begun to examine the processes by which expert athletes combine contextual priors and current visual information in order to facilitate rapid and accurate action anticipation (see Cañal-Bruland & Mann, 2015). Chapters 3 to 5 have demonstrated the effects of explicitly provided contextual priors on expert athletes' anticipatory judgements and the processing strategies employed during performance. The findings suggest that the impact of contextual priors is modulated by the reliability of both the priors themselves and the current visual information. This suggestion aligns with the proposal that athletes may use Bayesian reliability-based strategies to integrate contextual priors and visual information during action anticipation (Loffing & Cañal-Bruland, 2017). However, when examining anticipation in sport, a key, but often overlooked, component of the Bayesian framework is the comparative utility associated with possible judgements. Judgement utility refers to the costs and rewards associated with the consequences of one's judgements: high judgement utility is associated with high rewards (if accurate) and low costs (if inaccurate), and vice versa. According to Bayesian theory, people not only strive to maximise the probability for their judgments to be accurate, but also to maximise the expected utility of their judgments (Geisler & Diehl, 2003). In the current study, we examined the impact of judgement utility on expert soccer players' integration of contextual priors and visual information during action anticipation.

Bayesian models for probabilistic inference suggest that people integrate contextual priors and evolving visual information according to the comparative levels of reliability associated with the different sources of information (Vilares & Körding, 2011). However, another fundamental aspect of Bayesian theory is that an individual's ultimate decision is also affected by the potential costs and rewards associated with inaccurate and accurate responses, respectively. In Bayesian terms, the weighted average of the reliability of the informational variables at hand is convolved with the utility values assigned to possible judgements, where the optimal judgement is the one that maximises the probable utility (Geisler & Diehl, 2003). The biasing effect of judgement utility is not only due to people's desire to gain rewards and avoid costs but is also because people tend to assume that current information is more confirmative of the outcome in line with the highest utility and, as such, they overestimate the likelihood of that outcome happening (see DeKay et al., 2009; Russo & Yong, 2011). The biasing effect of judgement utility was, for example, shown in a study by Wallsten (1981) in which physicians judged it to be more likely that a patient had a malignant tumour than a cyst, despite the higher objective likelihood that the patient was having a cyst. It was proposed that the physicians overestimated the chances of a tumour, due to its more severe consequences, relative to a cyst. In other words, diagnosing a tumour would come with greater rewards (if correct) and lower costs (if incorrect) than would diagnosing a cyst.

Within the sporting domain, Canãl-Bruland and colleagues (2015) found that skilled baseball batters tended to predict that fastballs would be pitched to a greater extent than change-ups. It was suggested that this strategy enabled them to not only handle the high speed of a fastball, but also, due to the slower nature of change-ups, to adapt their swing if confronted with this latter pitch type. Expecting a change-up, on the other hand, would not allow the batter to catch up with the speed of a fastball. This finding suggests that judgement utility (e.g., comparatively higher utility of predicting a fastball than a change-up in baseball) may influence athletes' anticipatory judgements. However, the extent to which judgement utility modulates the impact of contextual priors and athletes' processing priorities during task performance needs to be further examined; as such, an insight could be of practical value when seeking to predict the utility of contextual priors under conditions where inaccurate and accurate judgements are associated with various levels of costs and rewards, respectively (see Canãl-Bruland et al., 2015). Further understanding of the costs and rewards associated with athletes' judgements, will also facilitate the development of an overreaching theoretical framework of anticipation in sport (Cañal-Bruland & Mann, 2015).

By the means of eye-movement recordings (Chapter 3) and temporal occlusion (Chapter 4), it was inferred that expert soccer players used explicitly provided contextual priors to allocate their overt visual attention toward the players off the ball and away from the opponent's kinematics early in the trial. They then used the information about the positioning of the attacker off the ball to inform their early judgments according to the opponent's action tendencies. Later in the trial, closer to the point of action, it was proposed that the players used confirmatory or conflicting kinematic information from the opponent to either reinforce or change their judgments. Chapter 5 suggested that this process was cognitively demanding; however, the techniques utilised so far in this thesis does not allow for an in-depth understanding of this process. A technique that has been used to explore athletes' information processing priorities is to collect retrospective verbal reports of the thoughts they employed during the task, so-called retrospective think-aloud reports (see Eccles, 2012). This latter approach may be particularly advantageous when examining the role of non-visual information, such as contextual priors and judgement utility, during task performance. The retrospective think-aloud protocol was employed by Runswick and colleagues (2018a) in order to assess the impact of contextual priors on cricket batters processing priorities while predicting the location of bowlers' forthcoming deliveries. In the presence of contextual priors, expert batters reported a higher number of thoughts related to these prior sources of information (i.e., bowler's action tendencies, game state, and field setting) and fewer thoughts related to the bowler's kinematic information, compared to in the absence of contextual priors. Runswick and colleagues (2018b) used the same anticipation task and combined the collection of retrospective information score rating with a temporal occlusion paradigm. The batters' reported to predominantly rely on contextual priors during the early stages of the bowler's run-up, whereas they relied more on the bowler's kinematic information and the ball flight nearer to the point of ball release. The previous findings in the literature support the suggestion in this thesis that the reliability of the information sources dictates processing priorities, but this is yet to be explored with regards to the impact of judgement utility.

In the current study, retrospective think-aloud reports were used to gain a further insight into the processing priorities used by expert soccer players during action anticipation. The same task employed in Chapter 3 to 5 was employed: a video-based anticipation task simulating 2-versus-2 defensive soccer scenarios, in which the players had to predict the direction (left or right) of an oncoming opponent's action at the end of the video. However, in addition to conditions with and without explicitly provided contextual priors pertaining to the opponent's action tendencies (dribble = 70%; pass = 30%), a third condition was added in which contextual priors were explicitly provided *and* judgement utility was explicitly manipulated (left = high utility; right = low utility).

It was hypothesised that the players would employ reliability-based strategies to integrate contextual priors, visual information, and judgement utility to inform their anticipatory judgments (see Geisler & Diehl, 2003; Vilares & Körding, 2011). Specifically, it was predicted that the explicit provision of contextual priors would result in that players engaged in more thoughts related to the positioning of the attacker off the ball and the opponent's action tendencies, whereas fewer thoughts would be related to the opponent's kinematics. In line with the findings reported in Chapter 3 to 5, it was predicted that these additional thought processes would result in enhanced anticipation efficiency, driven by a beneficial effect on congruent trials, while no substantial impact would be found on incongruent trials. In the novel condition where judgement utility was manipulated, it was hypothesised that the players would engage in more thoughts related to the costs and rewards that their responses could bring about, and fewer thoughts related to the opponent's action tendencies and relevant visual information. In keeping with Bayesian theory (see Geisler & Diehl, 2003), it was predicted that this effect would lead to the players' judgements being less influenced by contextual priors and emerging kinematic information; instead, players would be more inclined to opt for the direction associated with a higher utility value (i.e., 'left').

6.3 Methods

6.3.1 Participants. A total of 10 male and 8 female expert soccer players (M_{age} = 23 years, *SD* = 3) took part in the study. This sample size is comparable to those used in Chapter 3 to 5, where clear effects of explicit contextual priors on expert players' anticipation performance were found. On average, the players had 14 years' (*SD* = 2) competitive experience in soccer and participated in 9 hours (*SD* = 4) of practice or match play per week. The study was approved by the College of Health and Life Sciences Research Ethics Committee (see Appendix 5) and the Institutional Review Board of the University of Utah (see Appendix 6). The study conformed to the recommendations of the Declaration of Helsinki and all participants gave their written informed consent before they took part in the study.

6.3.2 Test stimuli and task. The same soccer scenarios that were used in Chapter 3 to 5 were used as test stimuli in the current study. The final test footage comprised 30 video clips that were projected onto a 3.3 x 1.9 m projection screen using an Optoma HD20 DLP projector (Optoma, New Taipei City, Taiwan). Each video sequence lasted for 5 s and, at the end of each sequence, the opponent could either pass the ball to his teammate who was positioning either on the left or the right side of the opponent (30% of trials) or dribble the ball in the opposite direction (70% of trials). The task for the participant was to predict the direction (left or right) of the opponent's final action. At the start of each trial, the participant was standing 3.5 m in front of the projection holding one response device equipped with a response button in each hand; one for 'left' responses and one for 'right' responses. The participant was instructed to respond as soon as they were certain enough to carry out an action based on their prediction and that they could not change this response. Immediately after the participant's response, the trial was occluded and feedback for response time and accuracy was displayed on-screen. A full 5-s trial was occluded 120 ms after the foot-ball contact of the opponent's final action and if the participant responded after this point, then that trial was counted as incorrect. During the course of a trial, the participant was free to move as they preferred in order to maximise the real-world representativeness of the task (cf. Roca et al., 2011).

6.3.3 Procedure. Prior to testing, the participant took part in 25- 40-min of training on how to provide retrospective think-aloud reports. This training consisted of instructions on how to report thoughts retrospectively, including a number of generic tasks that the participant was given the opportunity to practise. The participant was given feedback on their verbal reports, along with good and bad examples for these practice tasks (for further details on training participants to provide valid verbal reports of thoughts, see Eccles, 2012). Throughout the training, the participant was encouraged to ask the researcher questions if they were unsure about how to articulate their reports. Following this training, the participant was fitted with a lapel microphone and a body-pack transmitter that was wirelessly connected to a compact diversity receiver (ew112-p G3; Sennheiser, Wedemark, Germany) and a recording device (Zoom H5; Zoom Corporation, Tokyo, Japan), so that verbal reports could be recorded. Thereafter, the participant was given an overview of the experimental protocol and performed eight familiarisation trials to become accustomed to the experimental setup and response requirements. Verbal reports of thoughts were collected after four of those familiarisation trials.

Following the familiarisation trials, the 30 test trials were presented in three blocks of ten trials, and under three different conditions (i.e., 90 test trials in total). In the control condition (*CTRL*), the participant performed the task without any additional information. In one of the experimental conditions (*EXP*), the participant performed the same task, but prior to each block, the participant was explicitly primed (verbally and on-screen) with contextual priors pertaining to the opponent's action tendencies (i.e., dribble = 70%; pass = 30%). In the other experimental condition (EXP^{JU}), the same task was performed, and the same contextual priors were explicitly provided, but in this condition, the participant was instructed that if they were incorrect (i.e., responded 'right') when the opponent passed or dribbled the ball toward the left, their team would concede a goal – and that they should try to avoid that. This instruction was given in order to increase the comparative utility associated with responding 'left'. In other words, correct and incorrect 'left' responses came with greater rewards (stopping a goal) and costs (conceding a goal), respectively, than 'right' responses. This manipulation was based on the fact that in soccer, possession of the ball in a more central position near the penalty area, to the participant's left in the present task, is more strongly associated with positive attacking outcomes than possession in a wider position (to the participant's right), further from the goal (Brooks, Kerr, & Guttag, 2016). The participant received this instruction prior to each block, both verbally and on-screen, and was informed as to the number of goals they had conceded after each block.

Each condition started with a condition-specific familiarisation trial, for which retrospective verbal reports were collected. The order in which the conditions were presented was randomised and counterbalanced across participants. To eliminate the influence of trial-specific characteristics, the same test trials were used in all three conditions. Thus, the distribution of trials where the opponent dribbled (70%) and passed (30%) the ball was identical in the three conditions. Furthermore, these actions were equally distributed across left and right outcome directions. To avoid any potential familiarity between conditions, the trial order in each condition was randomised. Response time and accuracy were recorded for each trial and verbal reports of thoughts were collected after six trials in each condition[1] (cf. Runswick et al., 2018a). The whole test session was completed within 90 min.

6.3.4 Data analysis. The anticipation performance was expressed by an anticipation efficiency score which, in keeping with Chapters 3 and 5, was calculated by multiplying the average response time by the proportion of inaccurate responses in each condition (note: lower efficiency score indicates superior anticipation efficiency). The impact of explicit contextual priors on anticipation efficiency was assessed by comparing the condition with no explicit priors to the conditions in which the explicit priors were provided with (EXP^{JU}−CTRL) and without (EXP−CTRL) explicit manipulations of judgement utility. As it was predicted that anticipation efficiency would be modulated by the congruency between the opponent's action tendencies and the final action, both combined and separate analyses of congruent and incongruent trials were carried out. Furthermore, to assess the effect of outcome direction within each condition, the proportion of 'left' responses was compared across the three conditions.

The verbal reports of thoughts were first transcribed verbatim, and the statements conveyed by each report were then coded into different categories (cf. Murphy et al., 2016; Roca et al., 2013; Runswick et al., 2018a). Statements were coded into three categories of visual information: *positioning of the attacker off the ball*, statements referring to the horizontal position (e.g., left, right, inside, outside) of the attacker off the ball relative to opponent; *kinematic information*, statements referring to the kinematic cues from the oncoming opponent; *other visual information*, statements referring to other kind of visual information not captured by the previous two categories. Furthermore, statements were coded into two categories of non-visual information: *action tendencies*, statements referring to the opponent's tendency to pass or dribble the ball; *judgement utility*, statements referring to the

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[1] The selection of trials for which verbal reports were given was pseudorandomised in order to counterbalance the number of trials where the opponent dribbled (n =3) and passed (n = 3) the ball, as well as the number of trials where the direction of the final actions was left (n = 3) and right (n = 3). The same trials were selected for all conditions and participants in order to avoid trial-specific characteristics from violating the verbal-report data.

costs and/or rewards their responses could bring about. Verbal report data from 3 participants, and 9 reports (< 4%) from the remaining 15 participants, were excluded from the analyses due to not following the procedure required for giving retrospective think-aloud reports (see Eccles, 2012). Once statements within each eligible report had been categorised, the proportion of reports containing statements of each category for each condition was assessed (cf. Murphy et al., 2016). Due to high variability across participants leading to vastly skewed data, inferential statistical analyses were not conducted on the reports; thus, only descriptive statistics were presented.

6.3.4.1 Statistical analysis. Descriptive statistics are reported as means and *SD*s, while magnitudes of observed effects are reported as standardised (*d*) and unstandardised units. Uncertainties in true effects were reported as 90% CIs. Effects were standardised by dividing the mean difference between conditions by the combined *SD* (Cumming, 2012) and then interpreted against the following scale: $0.2 > |d|$, trivial; $0.2 \leq |d| < 0.5$, small; $0.5 \leq |d| < 0.8$, moderate; $0.8 < |d|$, large (Cohen, 1988). Cohen's standardised unit for the smallest substantial effect (0.2) was used as a threshold value when estimating the uncertainty in true effects. The following scale was used to convert the quantitative chances to qualitative descriptors: 25-75%, possible; 75-95%, likely; 95-99.5%, very likely; > 99.5%, most likely (Hopkins, 2002). If the lower and upper bounds of the CI exceeded the thresholds for the smallest substantial negative and positive effect, respectively, then the effect was deemed unclear. All other effects were where deemed clear and evaluated as per the description above (Batterham & Hopkins, 2006).

6.4 Results

6.4.1 Anticipation performance. Table 6.1 shows the descriptive statistics for the response time and accuracy scores that were used to calculate the anticipation efficiency score in each condition. As shown in Figure 6.1, superior performance, expressed by a lower overall efficiency score, was found in EXP than in CTRL ($d = 0.54 \pm 0.35$), whereas no substantial effect was obtained when CTRL and EXP^{JU} were compared ($d = 0.14 \pm 0.34$). Separate analyses of congruent trials showed superior efficiency in EXP, relative to CTRL ($d = 0.54 \pm 0.39$), while no clear effect was found between CTRL and EXP^{JU}. For incongruent trials, a beneficial effect was obtained when the anticipation efficiency score in EXP^{JU} was compared to that in CTRL ($d = 0.51 \pm 0.39$), but no clear effect was found between CTRL and EXP. Unstandardised effects for the anticipation efficiency scores in EXP and EXP^{JU}, compared to those in CTRL, are presented in Table 6.2.

To explore the effect of outcome direction within each condition, the proportion of 'left' responses was compared across the three conditions. Figure 6.2 shows that the proportion of 'left' responses were higher in CTRL than in EXP (*d* = 0.33 ±0.42) and higher in EXP^{JU}, both compared to CTRL (*d* = 0.65 ±0.44) and compared to EXP (*d* = 1.03 ±0.47).

Table 6.1

Descriptive Statistics (M ± SD) for Response Time and Accuracy in Each Condition

	CTRL	EXP	EXP^{JU}
Response time (ms)			
Overall	4,416 ± 518	4,316 ± 756	4,405 ± 453
Congruent	4,383 ± 526	4,288 ± 752	4,372 ± 447
Incongruent	4,493 ± 503	4,379 ± 773	4,482 ± 496
Response accuracy (%)			
Overall	63 ± 13	67 ± 10	65 ± 11
Congruent	77 ± 18	84 ± 11	75 ± 15
Incongruent	31 ± 28	28 ± 16	40 ± 15

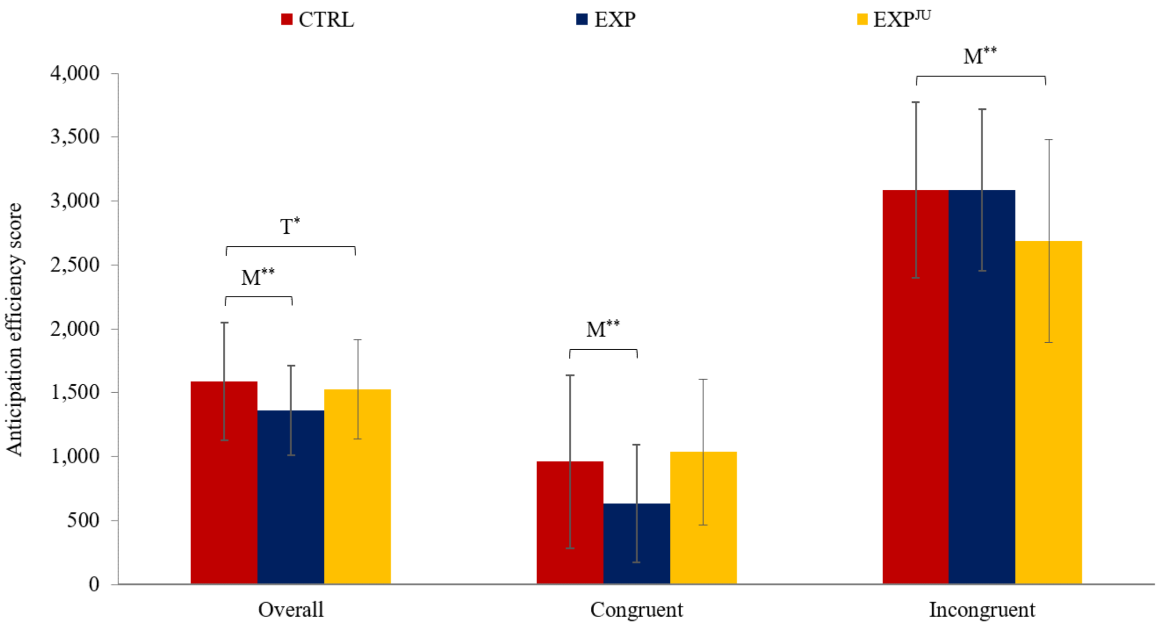

Figure 6.1. Anticipation Efficiency. Means and *SD*s for the anticipation efficiency score in each condition, as well as inferences of observed and true effects of explicit contextual priors without (EXP−CTRL) and with (EXP^{JU}−CTRL) manipulated judgement utility (note: lower efficiency scores indicate superior anticipatory efficiency). Inference of observed effects: 0.2 > |*d*|, trivial (T); 0.5 ≤ |*d*| < 0.8, moderate (M). Inference of uncertainty in true effects: * possibly (25-75%); ** likely (75-95%).

Table 6.2

Unstandardised Effects (M ±90% CI) of Explicit Contextual Priors on Anticipation Efficiency under Conditions Without (EXP−CTRL) and With (EXP^{JU}−CTRL) Manipulated Judgement Utility

	Without manipulated judgement utility			With manipulated judgement utility		
Overall	−230.6	±	152.1	−63.6	±	149.9
Congruent	−328.1	±	237.2	75.0	±	248.6
Incongruent	−1.5	±	345.8	−398.2	±	300.0

Note: lower anticipation efficiency score indicates superior anticipation efficiency.

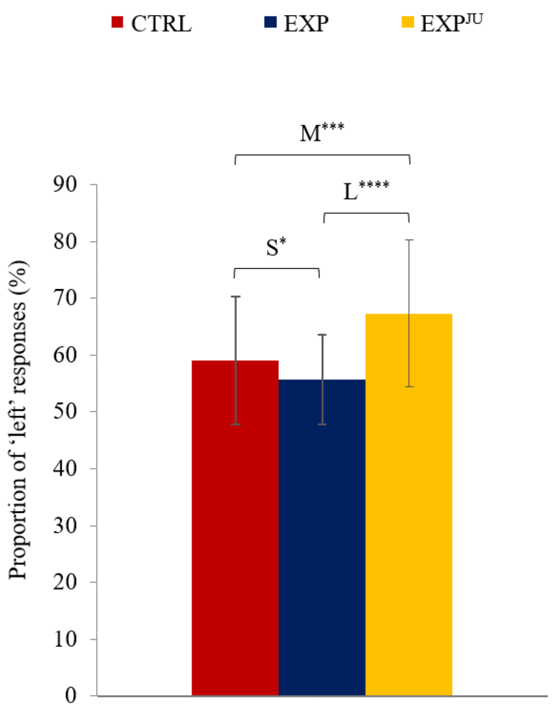

Figure 6.2. Proportion of 'Left' Responses. Means and *SD*s for the proportion of 'left' responses in each condition, as well as inferences of observed and true effects between conditions. Inference of observed effects: $0.2 \leq |d| < 0.5$, small (S); $0.5 \leq |d| < 0.8$, moderate (M); $0.8 < |d|$, large (L). Inference of uncertainty in true effects: * possibly (25-75%); *** very likely (95-99.5%); **** most likely (> 99.5%).

6.4.2 Verbal reports of thoughts. Descriptive statistics revealed that 71.1% (*SD* = 35.0) of the reports in CTRL contained references to the opponent's kinematic information. The corresponding proportions in EXP and EXP^{JU} were 50.1% (*SD* = 32.0) and 33.3% (*SD* = 34.1), respectively. The proportion of reports containing references to the positioning of the attacker off the ball were 54.0% (*SD* = 35.3) in CTRL, 68.2% (*SD* = 37.1) in EXP, and 59.1% (*SD* = 41.8) in EXP^{JU}. Statements referring to other visual information were reported in 52.4% (*SD* = 36.9) of the reports in CTRL, while the corresponding figures were 39.8% (*SD* = 36.9) and 37.3% (*SD* = 35.1) in EXP, and EXP^{JU}, respectively. With regard to reports containing statements referring to non-visual information, the proportion of reports containing statements relating to the opponent's action tendencies were 1.1% (*SD* = 4.3) in CTRL, 32.2% (*SD* = 28.5) in EXP, and 22.2% (*SD* = 29.5) in EXP^{JU}. Statements relating to judgement utility were reported in 34.2% (*SD* = 32.5) of the reports in EXP^{JU}, while the corresponding proportions in CTRL and EXP were 14.2% (*SD* = 23.3) and 3.3% (*SD* = 12.9), respectively.

6.5 Discussion

I examined the impact of judgement utility on the integration of contextual priors and visual information during action anticipation in sport. Expert soccer players were required to predict the direction (left or right) of an oncoming opponent's imminent actions. The players performed this task under three different conditions: one condition without any explicit contextual priors; another condition in which contextual priors pertaining to the opponent's action tendencies were explicitly provided; and a third condition where contextual priors were explicitly provided, *and* judgement utility was explicitly manipulated (left judgements = high utility; right judgements = low utility). Anticipation performance as well as retrospective think-aloud reports were collected in the three conditions.

In line with the predictions, it was found that the explicit provision of contextual priors came with enhanced overall anticipation efficiency and that this effect was driven by enhanced efficiency on congruent trials, whereas no clear substantial effect was found on incongruent trials. These findings support those reported in the previous chapters suggesting that experts use explicit contextual priors to enhance performance, but can also compensate for the biasing effect of the priors when the opponent exhibits conflicting kinematic information (see also Broadbent et al., 2018). To further explore the processing priorities during task performance, the current study utilised immediate retrospective verbal reports of the thought processes the players employed. Although no inferential statistical analyses were run, descriptive data revealed that the players referred to the opponent's action tendencies to a greater extent when this information was explicitly provided, compared to when it was not. These findings concur with those collected in a study by Runswick and colleagues (2018a), in which cricket batters provided more statements relating to the bowler's prior action tendencies when viewing the same bowler consecutively, relative to when six different bowlers were shown.

Furthermore, Runswick and colleagues (2018a) found that increased reliance upon the opponent's action tendencies came with fewer statements referring to the kinematic information of the opponent. The current study shows support for this finding, as the proportion of thoughts relating to the opponent's kinematic information was lower when contextual priors were explicitly provided, relative to when they were not. Descriptive statistics showed that the players reported a higher proportion of thoughts relating to the positioning of the attacker off the ball when explicit contextual priors were provided, compared to when they were not. In conjunction with increased attention toward the attacker off the ball, the explicit provision of contextual priors drew the players' attention away from the oncoming opponent. This finding aligns with the gaze data reported in Chapter 3, in which the expert soccer players allocated their overt visual attention toward the attacker off the ball as this contained vital information in order to enable the players to use the contextual priors and ultimately inform their anticipatory judgements in accordance with this. This interaction of prior and current sources of information aligns with the Bayesian notion that when the reliability of one informational variable increases (e.g., increased reliability of contextual priors via explicit guidance or sequential pickup), people's judgements become less contingent upon other informational variables (e.g., kinematic information; see Knill & Pouget, 2004).

The current study also examined the extent to which judgement utility affected players' anticipation and their processing priorities during task performance. In keeping with Bayesian theory (see Geisler & Diehl, 2003; Vilares & Körding, 2011), it was hypothesised that the players' concern about the positive and negative consequences that their responses could bring about would increase the players tendency to respond 'left', as this option came with comparatively higher utility than responding 'right'. As predicted, the proportion of responses where the players opted for a leftward outcome was higher under conditions where the judgement utility was explicitly manipulated, compared to when it was not. Such biasing effect of judgement utility has been demonstrated across various domains (see Canãl-Bruland et al., 2015; DeKay et al., 2009; Russo & Yong, 2011). Interestingly, in the study by Canãl-Bruland and colleagues (2015), baseball batters were not explicitly told that certain actions from the pitcher came with greater utility, but yet a bias was found. This aligns with the finding in the current study, that the players responded 'left' more often than 'right' in all three conditions, which could be explained by the fact that the left side is associated with greater goal threat due to the position on the pitch, even if this information was not explicitly provided. It is noteworthy that, in the two conditions where judgement utility was not explicitly manipulated, the players were more inclined to respond ‘left’ in the condition without explicit contextual priors, compared to the condition with explicit priors. In keeping with Bayesian theory (see Geisler & Diehl, 2003; Vilares & Körding, 2011), it is reasonable to believe that this perceived imbalance in threat between left and right outcomes was weighted higher in the former condition where less reliance was placed on the opponent’s action tendencies.

An important objective for this study was to examine the moderating effect of judgement utility on the extent to which explicit contextual priors affected the players’ anticipation performance. As predicted, the beneficial effects of explicit priors on anticipation efficiency were not found in the condition where the judgement utility was manipulated. The retrospective verbal reports of thoughts provide tentative support that the supressing effect of judgement utility was underpinned by changes in the thought processes that the players employed during task performance (see also DeKay et al., 2009; Russo & Yong, 2011). In the condition where judgement utility was manipulated and explicit contextual priors were provided, the players engaged in fewer thoughts relating to the positioning of the attacker off the ball (i.e., information that enabled the players to use the contextual priors), compared to when explicit contextual priors were provided but judgement utility was not manipulated. Furthermore, in the former condition, the players reported that they relied less on the opponent’s kinematic information, relative to the other two conditions. In line with our predictions, the descriptive data suggest that this decreased reliance upon relevant sources of visual information and contextual priors was due to increased concern about the costs and rewards their responses could bring about.

In summary, the findings of this study suggest that expert athletes use reliability-based strategies to integrate contextual priors, visual information, and judgement utility during action anticipation. Namely, explicit provision of contextual priors biases athletes’ processing priorities, such that greater reliance is placed on context-relevant visual information, while less reliance is placed upon evolving kinematic information. This, in turn, biases the athlete’s anticipatory judgement toward the most likely outcome, given the contextual priors. However, the biasing impact of explicitly provided contextual priors, in regard to both anticipation performance and the associated thought processes, becomes supressed when the comparative utilities of potential outcomes differ. Under such conditions, the athlete becomes less reliant upon the reliability conveyed by contextual priors and unfolding visual information, and more inclined to opt for the outcome that could generate the highest rewards (if correct) and lowest costs (if incorrect). These novel findings offer practical implications with regard to the utility of contextual priors under various performance conditions (see also Canãl-Bruland et al., 2015) and contribute to an overreaching theoretical framework that is capable of predicting anticipatory behaviours in sport (Cañal-Bruland & Mann, 2015).

Chapter 7: Epilogue

In this chapter, I summarise the objectives of the present research programme and provide a synopsis of the main findings from its four experimental studies. Theoretical, methodological and practical implications are discussed, along with potential limitations and future research directions.

7.1 Objectives of the Thesis

The overarching aim of the present programme of research was to gain further insight into expert athletes' integration of contextual priors and visual information during action anticipation under various performance conditions. In order to achieve this aim, four experimental studies were conducted, in which soccer players had to predict the forthcoming actions of an oncoming opponent – with and without explicit contextual priors pertaining to the opponent's action tendencies.

Chapter 3 examined skill-level differences with regard to the impact of explicit contextual priors on anticipation performance and the processing strategies employed during task operation. The players' distribution of visual dwell time was recorded, and their anticipatory judgements were tracked across task performance. Additionally, retrospective ratings of perceived cognitive load invested in the task were obtained.

Chapter 4 further explored the extent to which the relative reliabilities associated with explicit contextual priors and evolving visual information affected expert players' anticipatory judgements. This was achieved by altering the strength of the opponent's action tendencies and, via progressive temporal occlusion, the availability of relevant kinematic information.

Chapter 5 further investigated the impact of contextual priors on expert players' cognitive load. Retrospective ratings of perceived cognitive load were compared with EEG recordings of cortical activity during task performance. Furthermore, the extent to which the performance effects of explicit contextual priors were modulated by task load was examined.

Finally, Chapter 6 manipulated the potential costs and rewards associated with different response outcomes, in order to examine the impact of judgement utility on expert players' anticipatory judgements. Additionally, further insight into the processing priorities that the players employed during task performance was sought by collecting verbal reports of thoughts immediately after task completion.

7.2 Synthesis of Findings

7.2.1 Performance effects. A consistent finding across the four studies was that explicit contextual priors had a beneficial effect on expert players' ultimate anticipatory judgement. This beneficial performance effect was driven by enhanced performance on congruent trials in which the opponent performed the most likely action, given his action tendencies, whereas no clear substantial change was found for incongruent trials. Importantly, in Chapter 3 it was revealed that explicit contextual priors had a biasing effect on experts', but not on novices', online anticipatory judgements, and that novices', but not experts', ultimate judgements for incongruent trials were negatively affected by explicitly provided contextual priors. It is also worth noting that the performance effects found for expert players were modulated by the reliability conveyed by the opponent's kinematics. Specifically, on incongruent trials, the explicit provision of contextual priors had a detrimental effect on the accuracy of expert players' online judgements in Chapter 3 and the accuracy of the judgements they made at the first occlusion point (i.e., after the first trial half) in Chapter 4. However, when the kinematic information was reliable (i.e., the ultimate judgement in Chapter 3 and the second occlusion point close to the final action in Chapter 4), expert players could use this information to update conflicting information from the contextual priors to maintain performance on incongruent trials.

In Chapter 4, it was also demonstrated that the impact of explicit contextual priors on expert players' judgements was not only modulated by the reliability of the opponent's kinematic information, but also by the reliability of the priors themselves. In this chapter, the magnitudes of the performance effects of explicit priors pertaining to strong and subtle action tendencies did not differ after the first half of the trial, when kinematic information was less reliable. However, only explicit priors pertaining to strong action tendencies yielded a beneficial performance effect after the second half of the trial when kinematic information was more reliable. Taken together, the findings in Chapter 3 and 4 suggest that the reliability, and therefore the impact, of the information at hand was moderated not only by the relevance of the information itself, but also by the players' ability to utilise this relevance.

7.2.2 Effects on processing strategies. In addition to its impact on anticipation performance, the explicit provision of contextual priors influenced experts', but not novices', information processing priorities during task performance. In Chapter 3, it was found that the provision of explicit priors altered expert players' allocation of overt visual attention such that they devoted more attention toward the players off the ball and less attention toward the opponent. Furthermore, this effect was only found over the first half of the trial, during which the opponent's kinematic information was not relevant to his final action and the direction change of the attacker off the ball occurred which provided information that enabled the players to use the contextual priors effectively. This finding suggests that the reliability of the opponent's kinematic information did not only moderate the performance effects of explicit contextual priors, but also their impact on the processing strategies employed by the players during task performance. The conditional integration of contextual priors and visual information was shown to increase the cognitive load during the task through the use of stringent EEG measures in Chapter 5. However, an opposite effect was revealed via the players' retrospective ratings of perceived cognitive load, which is something that will be discussed further in Section 7.3.

The change in processing priorities that expert players employed during task performance was also manifested in the players' retrospective verbal reports of thoughts collected in Chapter 6. Although only descriptive data were reported, the proportion of verbal statements referring to the opponent's kinematic information was lower when contextual priors were explicitly provided, relative to when they were not. Furthermore, in the former condition, the players reported a higher proportion of thoughts relating to the positioning of the attacker off the ball, compared to in the latter condition. Taken together, the findings in this thesis suggest that the relative reliability of available sources of information impacted the players' processing priorities they employed during task performance and that the conditional integration of explicit contextual priors and visual information brought about increased processing demands.

7.2.3 Moderating factors. In Chapters 5 and 6, it was demonstrated that the impact of explicit contextual priors and visual information was influenced by additional moderating factors. Chapter 5 showed that the beneficial performance effects of explicit priors diminished under conditions of high task load (i.e., when a cognitively demanding secondary task was introduced). Furthermore, when the explicit priors were accompanied with high task load, anticipation performance on incongruent trials declined, compared to when no contextual priors were provided, suggesting that the expert players were unable to update their biased judgements with conflicting kinematic information. As stated previously, the EEG data collected in this chapter suggest that the explicit provision of contextual priors came with increased cognitive load, which is assumed to be due to the integration of contextual priors with the kinematic cues. The additional task load from a secondary task was shown to disrupt this processing strategy and thus negatively affected performance.

In Chapter 6, it was also found that judgement utility moderated the players' reliance on contextual priors and visual information. The players' tendency to respond 'left' increased when they were instructed that they would concede a goal if they incorrectly responded 'right'. This biasing effect of judgement utility convolved the performance effects of explicit contextual priors such as the beneficial effects for overall performance and the performance on congruent trials diminished, whereas performance improved on incongruent trials. Descriptive data from the players' verbal reports imply that the comparative utility associated with 'left' and 'right' responses influenced their processing priorities during task performance. When judgement utility was explicitly manipulated, expert players reported a higher proportion of thoughts relating to the potential consequences of their judgements and a lower proportion of thoughts relating to the positioning of the attacker off the ball, the opponent's action tendencies, and the opponent's kinematics. Taken together, the findings in Chapter 5 and 6 suggest that task load and judgement utility distorted the players' integration of contextual priors and visual information and, as such, convolved the biasing effects of this information.

7.3 Implications of Findings

7.3.1 Theoretical implications. Previous attempts have been made to conceptualise expert anticipation performance in sport and its underlying mechanisms. Müller and Abernethy (2012) proposed a model that sought to explain the behaviours of expert and novice athletes in striking sports, when tasked with anticipating and intercepting opponents' forthcoming actions. The model proposes that athletes adapt their anticipatory judgements during task performance, in accordance with changes in the specificity of visual information. Specifically, athletes refine their judgements over time, as the reliability of evolving visual information with regard to the to-be-anticipated action increases. Furthermore, due to their superior attunement to task-relevant visual cues, experts seem to be better able to adjust their processing priorities and subsequent behaviours in relation to evolving visual information and, as such, they become better anticipators than their less skilled counterparts. While the paper by Müller and Abernethy (2012) highlighted the important role played by the athletes' a priori expectations and beliefs, their model did not account for the impact of such information when explaining the anticipatory processes of athletes. Furthermore, the sport-specific and linear nature of the model restricts its applicability to broader performance settings, including highly dynamic and information-rich environments in which information sources may interact in a non-linear fashion and where the level congruency between information sources may modulate the performance effects of the information at hand.

Due to the multidimensional nature of anticipation, there was a recent call for an overarching theoretical framework to explain athletes' anticipatory processes, including the potential impact of contextual priors and judgement utility on those processes. Particularly, researchers have been encouraged to further examine the manner in which these sources of non-visual information interact with evolving visual information under various performance conditions (Cañal-Bruland & Mann, 2015). It has been speculated that Bayesian theory may provide a suitable framework for this research area (Loffing & Cañal-Bruland, 2017). Bayesian models for probabilistic inference propose that people integrate available sources of information on the basis of their comparative reliabilities with regard to the to-be-anticipated event, where higher processing priority is assigned to information associated with comparatively higher reliability. Furthermore, Bayesian theory postulates that the joint estimate of the to-be-anticipated event is convolved by the potential costs and rewards associated with possible judgements, where people strive to maximise the utility of the potential consequences of their judgements (Geisler & Diehl, 2003; Vilares & Körding, 2011).

In keeping with these assumptions, the current thesis provides novel evidence that athletes use reliability-based strategies to integrate explicit contextual priors and visual information during action anticipation. The findings reported in Chapter 3 and 4 suggest that the biasing effects of explicit contextual priors on athletes' anticipatory judgements are modulated not only by the reliability of evolving visual information, but also by the reliability of the priors themselves. Reliability-based integration of contextual priors and visual information has previously been demonstrated with cricket (Runswick et al., 2018b) and baseball batters (Gray & Cañal-Bruland, 2018), but this thesis provides novel insight as to how congruency between priors and visual information of varying levels of reliability influences task performance. This insight emphasises that informational congruency may constitute an important component for a theoretical framework that is able to predict athletes' anticipation performance under various conditions.

The model by Müller and Abernethy (2012) suggests that athletes adapt their anticipatory judgements in accordance with the reliability of visual information available during task performance and, since experts are more attuned to task-relevant cues, they are more able to assess the reliability of this information than novices. The findings reported in Chapter 3 expand on this suggestion by incorporating the athlete's use of contextual priors when informing their judgements. The findings suggest that the athlete's ability to comprehend the relevance, and therefore the reliability, of the information at hand is modulated by the level of expertise. Specifically, it was demonstrated that, in the absence of highly reliable visual information, experts' judgements were biased by explicit contextual priors to a greater extent than novices. Importantly, it was found that experts used explicit contextual priors to inform their acquisition of visual information, which enabled them to use the priors more effectively than novices. While previous research has highlighted experts' superior use of contextual priors, relative to novices (e.g., Runswick et al., 2018a; Runswick et al., 2018b), the original task design employed in this thesis offers novel evidence that experts use contextual priors to inform their visual information processing priorities and to shape their anticipatory judgements over time, in accordance with the reliability of evolving visual information. Collectively, the findings reported in Chapter 3 highlight that a model for action anticipation in sport needs to account for the interdependency between expertise, the reliability assigned to contextual priors and visual information, and the processing priorities the athlete employs during task performance.

In addition to the components mentioned above, an overarching model for action anticipation in sport needs to incorporate other factors that may influence the athlete's anticipatory processes. The findings reported in Chapter 5 suggest that increased task load may disrupt processing priorities and the athlete's integration of priors and visual information and result in impaired anticipation performance. Another factor that is deemed to influence athletes' anticipatory judgements is the comparative utility of possible judgements. Previous research has suggested that judgement utility may bias the athlete's action anticipation (Canãl-Bruland et al., 2015) and, in support of this assumption, Chapter 6 provides novel evidence that the athlete's consideration of the potential costs and rewards of possible judgements reduces their reliance upon both contextual priors and visual information. These findings support the Bayesian notion that judgement utility disrupts people's assessment of the reliability conveyed by the informational variables at hand (Russo & Yong, 2011).

7.3.1.1 A Reliability-Based Model for Action Anticipation in Sport. Collectively, the current thesis provides support for the idea that Bayesian theory may provide a suitable framework to elucidate the processes by which athletes inform their judgments during action anticipation (Loffing & Cañal-Bruland, 2017). Figure 7.1 depicts a preliminary model, using a Bayesian network approach, to classify action anticipation in sport and to show how the different factors examined in this thesis may interrelate. The model suggests that the reliabilities assigned to contextual priors and visual information are contingent upon the relevance of the respective informational variables, the athlete's ability to utilise this relevance, and the congruency between the information at hand. It is proposed that the reliabilities assigned to contextual priors and visual information moderate the athlete's processing priorities and that these priorities, in turn, result in that refined reliabilities are assigned to available information sources. Furthermore, it is proposed that this prioritisation process is affected by task load and judgement utility. Finally, the model suggests that the relationship between processing priorities, informational congruency, and informational reliabilities vis-à-vis contextual priors and visual information regulate the athlete's joint reliability estimate – upon which they base their anticipatory judgement. I would like to stress that the development of this model does not follow a strict Bayesian network modelling approach, which relies on substantial data sets, and that its aim is to initiate conceptual discussions. I acknowledge that, in addition to the factors examined in the current thesis, several yet to be explored variables are likely to moderate athletes' anticipatory behaviours, which I will discuss in Section 7.4. These variables need to be identified and explored, in order to develop a comprehensive framework that enables researchers to formulate and test task-specific predictions with regard to action anticipation in sport.

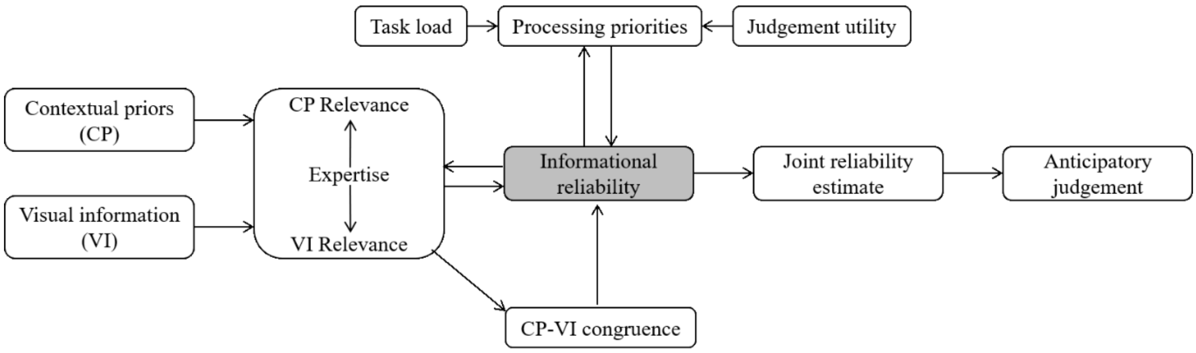

Figure 7.1. A Reliability-Based Model for Action Anticipation in Sport.

7.3.2 Methodological implications. A number of methodological factors deemed important for the study of athletes' integration of contextual priors and evolving visual information during action anticipation emerged in this thesis. In Chapter 3, the representative task, upon which the four experimental studies were based, was validated as capable of discriminating between performance of players of different skill levels. Unique to the task design was that the athletes were not able to use the contextual priors to inform their anticipatory judgements without integrating the priors with evolving visual information. Specifically, the players had to take into account the positioning of the attacker off the ball, which changed during the trial, in order to use the prior information about the opponent's action tendencies to inform their judgements. Cañal-Bruland and Mann (2015) emphasised the need to advance our understanding of how and when different sources of information enter anticipatory processes in complex and highly dynamic performance environments. This thesis, and the task used throughout, demonstrates that the interdependency between contextual priors and visual information may be an important component that needs to be considered when addressing these matters. Specifically, in combination with the online measures of visual dwell time and anticipatory judgements collected in Chapter 3, as well as the temporal occlusion paradigm adopted in Chapter 4, the original task design employed in these studies allowed for evaluation of the impact of contextual priors on processing strategies and anticipatory judgements in relation to the unfolding of pertinent visual information.

Using this task across all four studies, it was consistently found that the explicit provision of contextual priors did not negatively affect expert players' ultimate anticipatory judgement on incongruent trials (except under increased task load in Chapter 5). These consistent findings contradict those reported by Loffing and colleagues (2015) and Mann and colleagues (2014). In the current thesis, it is argued that expert players used their ability to pick up and interpret opponents' kinematics in the final stages of the trial and, as such, were able to use conflicting kinematic information to compensate for the otherwise negative bias of the explicit priors. It is possible that contrasting effects were obtained due to the fact that the previous research comprised different types of actions, with different spatiotemporal constraints accordingly, and so the availability of pertinent kinematic information differed across studies. Specifically, important kinematic information may have been occluded in the studies by Loffing and colleagues (2015) and Mann and colleagues (2014), which restricted the athletes' ability to update their context-biased beliefs with conflicting kinematic cues on incongruent trials. Hence, researchers adopting video-based task designs must carefully consider the utility of different occlusion points with regard to their specific research questions. It is reasonable to assume that the approach employed in Chapters 3, 5, and 6, wherein the players were instructed to respond when they felt certain enough to carry out an action based on their prediction, afforded greater real-world representativeness of the task, compared to the standardised occlusion points adopted in Chapter 4. However, in Chapter 4, standardised occlusion points were employed in order to control for the reliability of visual information available prior to each response. Importantly, the occlusion points selected in this chapter were dependent on the type of action the opponent performed at the end of the sequence (i.e., dribble or pass) rather than a standardised time point across both action types. This has not typically been done in the previous literature, but as the findings in Chapter 3 suggested that pertinent kinematic cues were revealed earlier on trials in which the opponent dribbled the ball, compared on trials where he passed it to his teammate, a later occlusion point was chosen for the latter set of trials in Chapter 4. The fact that the performance effects in the study in Chapter 4 aligned with those reported in the other chapters in the thesis, where response times were not standardised, suggests that the adoption of different occlusion points for various types of actions may be appropriate when employing the temporal occlusion paradigm in future sport anticipation research.

Another methodological implication relates to cognitive load and task load. Interestingly, this thesis revealed contrasting findings between the players' retrospective ratings of perceived cognitive load obtained in Chapter 5 (decreases in cognitive load) compared to those collected in Chapter 3 (no substantial effect), and the EEG data recorded in Chapter 5 (increases in cognitive load). This finding adds to the existing literature suggesting that subjective ratings of perceived cognitive effort may not be a reliable measure of cognitive load and that objective online psychophysiological measures may afford a more sensitive assessment of the cognitive load induced over certain time periods (e.g., over the first trial half) of task performance (Antonenko et al., 2010). The suggestion is that retrospective rating scales, such as the RSME, may in fact provide a measure of task difficulty rather than cognitive load (see Westbrook & Braver, 2015). Given the beneficial overall performance effect of explicit contextual priors, it is possible that the players perceived that the priors reduced task difficulty, regardless of the fact they required additional processing which ultimately increased cognitive load. The findings in Chapter 5 highlight concerns when using subjective ratings of perceived cognitive load and offers a neuroscientific technique which is deemed to provide a more stringent measure of cognitive load.

Chapter 5 also demonstrated that the beneficial impact of contextual priors diminished under conditions of high task load, which contradicts the findings of Runswick and colleagues (2018a). A possible explanation for these contrasting findings may link back to the interdependency between contextual priors and evolving visual information, which was present in the study in Chapter 5, but not in the study by Runswick and colleagues (2018a). That is, the decreased beneficial performance effects of explicit contextual priors that was revealed under high-task load conditions in Chapter 5, may have been due the processing demands induced by online integration of the opponent's action tendencies and the unfolding positioning of the attacker off the ball. However, these demands may not have been present in the study by Runswick and colleagues (2018a), in which the cricket batters could inform their judgements from the contextual priors alone, without having to integrate evolving visual information.

In summary, this thesis makes a number of methodological implications that future research should take in to consideration. Importantly, the interdependency between contextual priors and evolving visual information may be an important component to take into account when examining when and how the different information sources enter the anticipatory process. The necessity of integrating contextual priors with unfolding visual information in order to benefit from the priors may come with increased processing demands and should therefore be considered when assessing the impact of contextual priors under condition of high task load. With regard to capturing the cognitive load induced during task performance, the present thesis highlights the possible limitations of retrospective ratings and demonstrates the applicability of EEG as a more stringent technique for the assessment of cognitive load in sport. Finally, the current thesis highlights that different types of actions may convey various levels of reliability at any given time point, which needs to be considered when applying temporal occlusion paradigms in order to manipulate the reliability of evolving visual information.

7.3.3 Practical implications. From an applied perspective, this thesis furthers our understanding of the effects of providing contextual priors as part of elite sport preparation. This is common practice in the elite world of sport, wherein performance analysts creating reports on upcoming opponents – but, up to this point, little was known about the utility of such approaches. The consistent performance effects reported across the four studies support previous reports that expert athletes can use explicit contextual priors to enhance their anticipation performance (e.g., Broadbent et al., 2018; Gray & Cañal-Bruland, 2018; Navia et al., 2013). Importantly, the present thesis provides novel evidence that the integration of priors and pertinent visual information is modulated by several parameters that performance analysts and coaches need to consider when forecasting the usefulness of explicit contextual priors. Specifically, the findings in Chapter 4 suggest that, in conditions that force the athlete to predict opponents' actions in the absence of reliable kinematic information (e.g., under extreme time pressure), then priors may adversely affect performance. Furthermore, in Chapter 5 it was revealed that, when cognitive demands are high (as occurs under anxiogenic conditions; see Eysenck et al., 2007), the availability of working memory resources for integrating priors and visual information is limited, resulting in impaired performance. Also, Chapter 6 showed that changes in judgement utility, may suppress, or even override, the impact of priors and visual information on athletes' processing strategies and performance during action anticipation. Another finding that may have important practical implications when predicting the utility of explicit contextual priors is the expertise effect revealed in Chapter 3, which highlighted the potentially detrimental effects of providing this information if the athlete is not skilled enough to integrate and update it with conflicting kinematic information. This finding also highlights the importance of developing training protocols that focus on improving athletes' ability to pick up and use pertinent visual information which enables them to compensate for potentially negative biasing effects of contextual priors. The next section provides suggestions for how we might improve athletes' ability to integrate contextual priors with visual information.

7.4 Limitations and Future Research Directions

As with all scientific endeavours, there are limitations, and pertinent questions for future research, that have arisen during the evolution of this thesis. A limitation of the video-based anticipation task adopted throughout is the extent to which it represented the real-world performance environment (Pinder, Davids, Renshaw, & Araújo, 2011). It has been proposed that the use of laboratory-based video tasks may be limited, such that they fail to preserve the functional coupling between perception and action (e.g., Araújo, Davids, & Hristovski, 2006; van der Kamp, Rivas, van Doorn, & Savelsbergh, 2008). Others have suggested that the viewing perspective employed in laboratory-based video tasks may evoke processing strategies different from those used under natural performance conditions (e.g., Dicks et al., 2010; Mann, Farrow, Shuttleworth, & Hopwood, 2009). As such, there is a fundamental trade-off between the high experimental control (e.g., of reproducing sequences of action in a consistent manner from trial to trials and across athletes) of laboratory-based designs and the real-world representativeness of field-based designs. Researchers should strive to recreate the task constraints of the natural performance setting, but at the same time keep the task as repeatable and standardised as possible to allow for specific questions to be examined (Williams & Ericsson, 2005). In the present thesis, several actions were taken in an attempt to increase the real-world representativeness of the task employed across the studies. First, the video stimuli were filmed from the viewing perspective of the second defender in the 2-versus-2 soccer scenarios. Furthermore, in order to increase the realism of this perspective, the stimuli were filmed from a moving trolley; this reflects the changes in visual information that would occur in a typical match situation, in which a central defender faces oncoming opponents while simultaneously moving backwards. Second, the stimuli were projected onto a life-size projection screen/wall, rather than onto a small screen, which is deemed to recreate a more realistic performance environment when using video-based simulations (Williams & Davids, 1998). Third, in Chapters 3, 4, and 6, in order to increase movement fidelity of the task, the players were instructed that they could move around freely and as they preferred while performing the task, rather than be seated an passively respond to the stimuli (see Roca, Williams, & Ford, 2014). However, in Chapter 5, the players were instructed to remain seated and to avoid muscular contractions from compromising EEG data acquisition. Despite the attempts that were made to increase the representativeness of the experimental task employed throughout this thesis, the transferability of its findings to more natural performance conditions needs to be further confirmed – for example, via the implementation of field-based (see Müller et al., 2009; Müller & Abernethy, 2006) or virtual reality (see Craig & Watson, 2011; Vignais, Kulpa, Brault, Presse, & Bideau, 2015) designs.

A related issue is the potential limitation of the task stimuli used in the thesis: visual elements that would have been present under natural performance conditions were reduced. While a strength of the test stimulus employed in the current thesis is that it contained multiple players and that the relevance of visual information changed over the course of a trial, it is worth highlighting that a typical soccer match is far more complex, including a higher number of players and interactions between players. Also, under real-world performance conditions it is likely that players' anticipatory behaviours are affected by task-relevant information from other sensory modalities, such as sound (see Cañal-Bruland et al., 2018), which was not examined in this thesis. Thus, it is possible that the test stimuli did not evoke behaviours that would be exhibited in a more natural and complex performance environment. For example, it has been suggested that soccer players' visual search strategies differ according to the number of players within the visual display (Vaeyens, Lenoir, Williams, Mazyn, & Philippaerts, 2007). The complexity of the task may be of particular interest when examining the impact of contextual priors pertaining to opponent behaviours. In the current thesis, the contextual priors concerned the action tendencies of one specific opponent in one specific match scenario. However, in a real match, it is likely that the player is tasked with facing a variety of situations in which different contextual priors apply (e.g., different action tendencies for different opponents or for different areas of the field). Furthermore, in the current thesis, the players were faced with a two-choice task, whereas the outcome possibilities of real-world encounters may be far more diverse, which is likely to affect the players' anticipatory judgements (see Müller & Abernethy, 2012). Thus, future research should seek to explore the extent to which the impact of contextual priors is moderated by task complexity, in terms of visual scene complexity, crossmodal sensory processing, the variety of contextual priors provided/acquired, and the diversity of possible task outcomes.

The current thesis examined the moderating effects of task load, which may have practical implications for estimating athletes' anticipation performance under conditions of high-anxiety. It has been proposed that increased anxiety levels affect working memory by depleting attentional resources and thereby reducing the amount of free attentional capacity required for top-down, context driven, attentional control (Eysenck et al., 2007). On the other hand, it has been suggested that anxiety and contextual priors impact attentional resources through different mechanisms and, as such, increased anxiety levels do not disrupt athletes' use of contextual priors (Broadbent et al., 2018; Runswick et al., 2017). Given the important anxiety-performance relationship in sport and the ambiguous nature of current findings, the extent to which anxiety levels affect athletes' integration of contextual priors and visual information during action anticipation needs to be further explored. Additionally, it has been demonstrated that other factors related to an athlete's mental and physical state, such as arousal (Janelle, 2002) and physical fatigue (Royal et al., 2006), may affect their perceptual and cognitive performance. However, the ways in which these affect the athlete's reliance on contextual priors and visual information during action anticipation is yet to be examined.

The findings in this thesis highlight the importance of designing training protocols that enhances the athlete's ability to integrate contextual priors and visual information during action anticipation. However, the present thesis does not provide any directions for adequate instructional approaches and task manipulations of such training designs. While a significant amount of research has focused on perceptual training strategies in sport (for a review, see Hadlow, Panchuk, Mann, Portus, & Abernethy, 2018), less is known about the effectiveness of various approaches in which contextual priors are presented to the athlete. In one of the few studies to examine this, Gray (2015) compared the manner in which contextual priors were presented to baseball batters over a training period. It was shown that both full explicit provision of a pitcher's action tendencies, in the form of possible combinations of pitch count and pitch type, and cumulative build-up of this information (i.e., the explicit contextual priors only included the pitches the batter had faced up to that point in the training phase) improved batting performance, compared to when no contextual priors were explicitly provided. However, at a transfer test in which the batters were faced with a new pitcher that exhibited different action tendencies which had not been explicitly provided, only the cumulative training protocol yielded superior performance; full explicit provision of priors impaired performance, relative to the training period without explicit contextual priors. The author suggested that a possible explanation for the transfer findings could be that the cumulative approach may reinforce guided discovery learning, which facilitates the accumulation of contextual priors, even when these priors are not explicitly provided. While this suggestion may have practical implications for how to best introduce contextual priors in to training, future research needs to further explore its applicability across sport tasks of various constraints (e.g., the dynamics and complexity of the visual scene).

7.5. Conclusions

In summary, this thesis provides novel insights into athletes' integration of explicit contextual priors and visual information during action anticipation. In keeping with Bayesian models for probabilistic inference (see Vilares & Körding, 2011), athletes seem to integrate the different types of information sources in a reliability-based manner, where greater weight is given to sources of comparatively higher reliability. It seems to be the case that this comparative reliability biases the athlete's anticipatory judgements, as well as their processing priorities, during task performance. Importantly, the reliability assigned to available information seems to be contingent on not only its relevance with regard to the to-be-anticipated action, but also the athlete's ability to utilise this relevance. Effectively, expert athletes seem to integrate contextual priors to inform their acquisition of visual information more effectively than novices, resulting in superior anticipation performance. Also, experts seem to be able to use conflicting visual information in order to change their anticipatory judgements and, as such, avoid contextual priors from biasing their judgements negatively. Under performance conditions in which explicit contextual priors are accompanied with high task load, the integration of priors and visual information seems to be disrupted due to the cognitive load induced by this integration process, which consequently has a negative effect on anticipation performance. Notably, the processing demands of integrating contextual priors and visual information may not be picked up by retrospective ratings of cognitive load, while online psychophysiological techniques, such as EEG, may provide a more sensitive measure of the cognitive load invested during task performance. Furthermore, the potential costs and rewards associated with possible judgements may supress the athlete's reliance on both contextual priors and pertinent visual information, ultimately biasing their judgement toward the option associated with comparatively higher utility.

Collectively, the findings of this thesis have theoretical implications for the development of an overarching framework that can predict anticipatory behaviours in sport. Furthermore, this thesis provides valuable knowledge to sport coaches and performance analysts, by forecasting the utility of providing explicit contextual priors to athletes of various skill levels and under different performance conditions. Finally, the novel task design and online process measures employed in this thesis highlight important methodological considerations that researchers should take into account when looking to assess athletes' temporal integration of contextual priors and visual information during action anticipation.

Chapter 8: References

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Appendices

Appendix 1: Research Output (Chapter 3)

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Experts Integrate Explicit Contextual Priors and Environmental Information to Improve Anticipation Efficiency

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The understanding of how experts integrate prior situation-specific information (i.e., *contextual priors*) with emergent visual information when performing dynamic and temporally constrained tasks is limited. We used a soccer-based anticipation task to examine the ability of expert and novice players to integrate prior information about an opponent's action tendencies with unfolding environmental information such as opponent kinematics. We recorded gaze behaviors and ongoing expectations during task performance. Moreover, we assessed their final anticipatory judgments and perceived levels of cognitive effort invested. Explicit contextual priors biased the allocation of visual attention and shaped ongoing expectations in experts but not in novices. When the final action was congruent with the most likely action given the opponent's action tendencies, the contextual priors enhanced the final judgments for both groups. For incongruent trials, the explicit priors had a negative impact on the final judgments of novices but not experts. We interpreted the data using a Bayesian framework to provide novel insights into how contextual priors and dynamic environmental information are combined when making decisions under time pressure. Moreover, we provide evidence that this integration is governed by the temporal relevance of the information at hand as well as the ability to infer this relevance.

Public Significance Statement

This study suggests that soccer experts are superior to novices at combining explicit contextual priors with unfolding environmental information in order to efficiently predict future events. These novel findings elucidate the processes by which expert anticipators may assimilate multiple dynamic information sources in order to make rapid and accurate judgements in naturalistic contexts.

Keywords: Bayesian, decision making, probabilistic information, visual attention, sport

Supplemental materials: http://dx.doi.org/10.1037/xap0000174.supp

In many domains, individuals make predictive judgments about the world around them, often on the basis of ever-changing and partial information (Griffiths, Kemp, & Tenenbaum, 2008). To do so, they combine current environmental information with previously acquired situation-specific information, termed *contextual priors,* to formulate their decisions (Körding, 2007; Torralba, 2003). However, the use of these two information sources have typically been examined in isolation, and consequently, the impact of contextual priors on the use of current environmental information, and the associated cognitive demands of doing so, has largely been ignored (Vilares & Körding, 2011). Furthermore, due to the use of simple generic tasks and homogeneous groups of participants, the role that domain-specific expertise may play when integrating different sources of complex and evolving information has been overlooked (Brouwer & Knill, 2009; Miyazaki, Nozaki, & Nakajima, 2005; Tassinari, Hudson, & Landy, 2006). In the current study, we used a dynamic domain-specific simulation task to assess the impact of explicitly provided contextual priors on the processes and strategies used by expert and novice performers when anticipating the actions of others.

Individuals are frequently required to make accurate estimates about the state of an uncertain world that provides only probabilistic information about its actual state (Brunswik, 1952). A fundamental question, therefore, for human perception and cognition is how do people make inductive inferences that inform their subsequent behavior from typically incomplete information? In

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recent years, researchers have tried to answer this question using a Bayesian framework for probabilistic inference (for a review, see Rottman & Hastie, 2014). The fundamental concept behind the Bayesian approach is that the human brain combines confirmatory and conflicting pieces of ambiguous information to build abstract models of the world (Clark, 2013). It has been suggested that each informational variable provides a probability value referring to the state of a *hidden variable* and that people must effectively infer the resulting uncertainty to make accurate estimations about the hidden variable of interest (Knill & Pouget, 2004). For example, consider a doctor who is tasked with detecting a clinical disease (the hidden variable) on the basis of a patient's specific symptoms (the informational variables). A symptom is associated with a certain probability for and against potential diseases, which generates a joint probability distribution that informs the doctor's diagnosis.

Using Bayesian probabilistic inference, the individual strives to maximally reduce the total amount of uncertainty associated with the hidden variable (Vilares & Körding, 2011). It is thought that the joint probability distribution is derived from a weighted integration of the informational variables at hand. This process suggests that if one informational variable is associated with greater uncertainty than is another, the joint probability distribution should be biased toward the less uncertain variable (Knill & Pouget, 2004). For example, the doctor may consider visually salient symptoms (e.g., swelling) to be more relevant than are the patient's self-reported symptoms (e.g., pain). Although both information sources should be considered, the lower uncertainty associated with the former should be reflected in a more accurate estimate of the patient's clinical state.

Such weighted probabilistic inference has been explicitly demonstrated in simple spatial-location tasks (e.g., Alais & Burr, 2004; Battaglia, Jacobs, & Aslin, 2003; van Beers, Sittig, & Denier van der Gon, 1999) and perceptual-judgment tasks (e.g., Hillis, Watt, Landy, & Banks, 2004; Jacobs & Fine, 1999; Knill & Saunders, 2003). In more applied contexts, such as driving (Underwood, 2007), radiology (Krupinski, 2000), and playing soccer (Savelsbergh, Williams, Van Der Kamp, & Ward, 2002), it has been reported that players draw upon pertinent informational variables according to their relevance to the task at hand. Furthermore, it has been suggested that this weighted acquisition of information is contingent upon the individual's level of domain-specific expertise (Krupinski, 2000; Savelsbergh et al., 2002; Underwood, 2007). In other words, the relative uncertainties associated with the informational variables seem to depend on both their relationship with the hidden variable and the individual's ability to extract meaningful information from those variables. However, people do not typically make inductive judgments about the world from current environmental information alone; they also use contextual priors—the prior probability distribution that informs their estimate of the hidden variable (Griffiths, Vul, & Sanborn, 2012). For example, the doctor may study a patient's medical records before meeting the person face-to-face. This information is successfully integrated by expert doctors with the presenting symptoms to optimize diagnosis accuracy.

Although expertise and experience can endow an individual with contextual priors, such information can also be introduced into experimental designs (Seriès & Seitz, 2013). For example, contextual priors have been applied to simple arm-reaching (Brouwer & Knill, 2009), pointing (Tassinari et al., 2006), and event-timing (Miyazaki et al., 2005) tasks. In all of these studies, the participants combined prior and current information in a fashion that is predicted by Bayesian models. That is, they relied more on priors when the current environmental information was associated with greater uncertainty, and vice versa. Furthermore, it has been suggested that the addition of contextual priors biases the individual's allocation of attention by inducing a top-down, context-driven selection of environmental information (Torralba, 2003). This procedure has been demonstrated in law enforcement, where contextual priors biased not only participants' anticipatory judgments but also their allocation of visual attention toward context-relevant environmental information (Eberhardt, Goff, Purdie, & Davies, 2004).

However, the integration of contextual priors does not necessarily generate greater certainty of the joint estimate or enhance task performance; the priors may either conflict with environmental information or be invalid regarding the hidden variable. In dynamic and changing performance environments, as encountered in many sports, individuals' prior beliefs may lead them toward nonoptimal behaviors and judgments (Vilares & Körding, 2011). For example, using a video-based anticipation task, Loffing, Stern, and Hagemann (2015) showed that exposure to an opponent's previous action patterns biased anticipation of the opponent's next action in volleyball. The players' awareness of the opponent's action tendencies was beneficial only when the to-be-anticipated action was congruent with the preceding pattern (i.e., valid priors) but was detrimental when it was incongruent (i.e., invalid priors). Such dependency on congruent contextual priors has been demonstrated by exposing handball goalkeepers to the action tendencies of a penalty taker, before they were required to predict the direction of a penalty throw (Mann, Schaefers, & Cañal-Bruland, 2014). In both studies, the information about the opponent's tendencies was accrued in an implicit manner (i.e., the players did not receive explicit instructions or guidance). However, researchers have provided explicit information about the action tendencies of opponents to baseball batters (Gray, 2015) and soccer goalkeepers (Navia, Van Der Kamp, & Ruiz, 2013). In line with previous findings (Loffing et al., 2015; Mann et al., 2014), the explicit provision of contextual priors seems to be beneficial when the to-be-anticipated event is congruent with the prior information but detrimental when it is incongruent (Gray, 2015; Navia et al., 2013).

Loffing and colleagues (2015) reported that the congruence effect was more pronounced for expert than novice volleyball players. It may be that experts were superior to novices in utilizing available contextual information (cf. Farrow & Reid, 2012), but because the video footage was occluded 360 ms prior to hand–ball contact, they may not have been able to update their prior expectations with confirmatory or conflicting kinematic information from the opponent (cf. Loffing & Hagemann, 2014). Navia and colleagues (2013) found that prior information about the opponent's action tendencies had greater impact on goalkeepers who spent relatively less time attending to the opponent's kinematics. These findings collectively suggest that the impact of contextual priors, whether they are explicitly provided or are acquired in a more implicit manner, is subject to the individual's use of confirmatory or conflicting environmental information during task performance. The process by which this unfolds in a dynamic environment has yet to be examined (Cañal-Bruland & Mann, 2015). By furthering understanding of the anticipatory process and how it is informed by the congruence between contextual priors and evolving environmental information, one may extend the utility of a Bayesian framework when explaining how people weight available information sources in naturalistic and dynamic performance contexts. Moreover, knowledge of how this congruence effect interacts with the individual's ability to utilize available information sources may be used to inform adequate instructional approaches for practitioners at different skill levels.

In the current study, we used a dynamic performance context to provide unique insights into expertise-related differences in the ability to adapt one's judgments over time by integrating explicitly provided contextual priors with current environmental information (Loffing & Cañal-Bruland, 2017). The findings from this applied domain are discussed in line with a Bayesian framework for probabilistic inference to offer novel insight into the underlying perceptual and cognitive processes employed (Körding, 2007). Specifically, we used a two-versus-two video-based soccer task to examine how expert and novice players integrate contextual priors about an opponent's action tendencies with environmental information when anticipating the direction of an oncoming opponent's imminent actions. We recorded gaze behaviors and unfolding expectations to explore the perceptual and cognitive processes that underpin the anticipatory judgments. Also, we assessed the efficiency of the ultimate anticipatory judgment, as well as the perceived level of cognitive effort invested in the task.

We predicted that the explicit provision of contextual priors would increase visual dwell time on the players off the ball during the first half of the trial, because their positioning at this stage of the trial would contain context-relevant information (see the Method section for a detailed explanation; cf. Eberhardt et al., 2004; Torralba, 2003). This process would bias the online expectations when no other pertinent environmental information is available (cf. Brouwer & Knill, 2009; Miyazaki et al., 2005; Tassinari et al., 2006). This effect would be expressed by an increase in expectation accuracy when the opponent carries out the most likely action given the person's action tendencies (i.e., congruent trials) and a decrease in expectation accuracy when the opponent performs the least likely action (i.e., incongruent trials). We hypothesized that these biasing effects of explicit contextual priors would improve the efficiency of the ultimate anticipatory judgment on congruent trials but would impair the efficiency on incongruent trials (cf. Loffing et al., 2015).

Furthermore, we predicted that these effects would be moderated by expertise. We hypothesized that the effects on visual dwell time and online expectations would be more pronounced in experts compared to novices, due to the former group's superior ability to utilize context-relevant information compared to the latter group (Farrow & Reid, 2012). We predicted that the impairment of anticipation efficiency on incongruent trials would be less pronounced in experts because they would more effectively use evolving kinematic information from the player in possession to update expectations and inform their ultimate anticipatory judgment (cf. Savelsbergh et al., 2002). Consequently, we predicted that, due to better integration of contextual priors and environmental information, experts would anticipate more efficiently than novices on both congruent and incongruent trials. These predictions are in line with a Bayesian framework for probabilistic inference because players try to minimize the uncertainty of their final judgments by combining prior and current information, according to the relative uncertainty associated with the different sources of information (Körding, 2007). Finally, in line with previous suggestions (Green & Flowers, 2003), we predicted that the explicit provision of contextual priors would increase the perceived cognitive effort in all players.

Method

Participants

A total of 16 expert (M_{age} = 20 years, SD = 2) and 15 novice (M_{age} = 21 years, SD = 3) male soccer players participated. A spreadsheet for estimating sample size for magnitude-based inferences (Hopkins, 2006a) was used to calculate the number of participants needed to find a clear effect (i.e., chances of the true effect to be substantially positive and negative <5%; Hopkins, 2006b) on our main dependent measure (anticipation efficiency). We used data from a previous study (Roca, Ford, McRobert, & Williams, 2013) to calculate the minimum required sample size (Hopkins, Marshall, Batterham, & Hanin, 2009). This sample size is comparable to those employed in previous studies examining the perceptual and cognitive mechanisms that underpin anticipatory performance across expert and novice athletes (e.g., Jackson, Warren, & Abernethy, 2006; Murphy et al., 2016; Roca et al., 2013). The expert players had a mean of 11 years (SD = 2) of competitive experience in soccer and took part in an average of 8 hr (SD = 3) of practice or match play per week. The novice players were not currently playing at a competitive level and had an average of 2 years (SD = 2) of competitive experience. Research ethics committee approval was gained from the lead institution, and informed consent was obtained from all participants.

Test Stimuli

The video sequences were filmed on an artificial turf soccer pitch using a wide-angle converter lens (Canon WD-H72 .8x, Tokyo, Japan) attached to a high-definition digital video camera (Canon XF100, Tokyo, Japan). The video camera was attached to a moving trolley, at a height of 1.7 m, to closely replicate the perspective of a central defender in a typical match situation (i.e., facing oncoming opponents while simultaneously moving backward).

The sequences represented two-versus-two counterattacking scenarios in soccer. In each sequence, there was one attacking player in possession of the ball, a second attacker off the ball, and one defender marking the second attacker. Participants viewed all sequences from a first-person perspective, as if they were the second defender (see Figure 1). This scenario rapidly unfolds and presents a high level of perceived threat, which requires athletes to make frequent anticipatory behaviors (Triolet, Benguigui, Le Runigo, & Williams, 2013) and to increase their use of prior expectations (Roca et al., 2013), when compared to less pressured situations.

At the start of each sequence, the player in possession of the ball was positioned three meters inside the halfway line, approximately seven meters in front of the participant. The attacker off the ball and the marking defender started approximately three meters be-

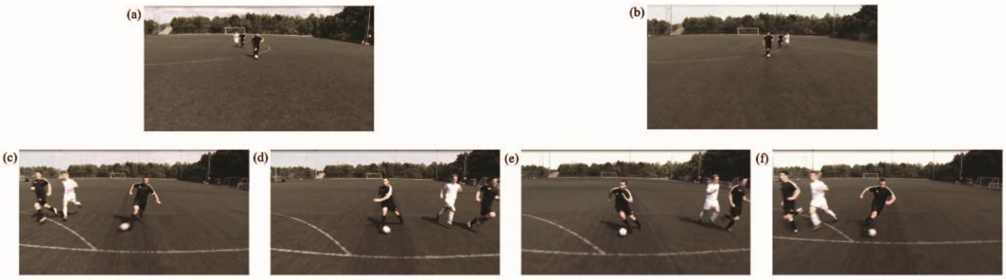

Figure 1. Test stimuli. The two different positions that the players off the ball could have at the start of each sequence: left-hand side of the player in possession (Panel a) and right-hand side of the player in possession (Panel b). The four different ultimate actions that the player in possession could carry out at the end of each sequence: pass left (Panel c), pass right (Panel d), dribble left (Panel e), and dribble right (Panel f). See the online article for the color version of this figure.

hind, on either the left or right side of the player in possession. Because players in a soccer match are normally aware of the relative positions of the ball and other players when they perform such tasks, each sequence started with a 1-s freeze frame to allow the participant to determine this information (cf. Roca, Ford, McRobert, & Williams, 2011). When the sequence started, the attackers approached the participant and, after approximately 1.5 s, the attacker off the ball made a direction change toward either the left or the right. At the end of the sequence, the player in possession was positioned approximately three meters in front of the participant. The attacker off the ball was level with the player in possession, to either his left or right. The marking defender followed the attacker off the ball throughout each sequence. At the end of each sequence, the player in possession either passed the ball to his teammate (33% of trials) or dribbled the ball in the opposite direction (67% of trials). The final position of the player off the ball was therefore informative regarding the direction of the final action (i.e., if the players off the ball were on the left side, 67% of the opponent in possession's final actions were to the right, and vice versa). A sequence lasted 4,960 ms and was occluded 120 ms after the player in possession's final action.

The footage was edited using Pinnacle Studio Software (2011; v15; Corel Corporation, Ottawa, Canada). In total, 130 video simulations were created. Two qualified soccer coaches (UEFA A License holders) independently selected the clips that they considered to be representative of actual game play. Only the clips that were selected by both coaches were included in the final test footage, making a total of 48 clips. These clips were projected onto a 4.1 × 2.3 m projection screen (AV Stumpfl, Wallern, Austria) using an NEC PE401H projector (NEC, Tokyo, Japan).

Task Design

The task for the participant was to predict the direction (left or right) of the player in possession's final action quickly and accurately. Also, over the course of each trial, participants were required to indicate their ongoing expectations regarding the direction of the final action. At the start of each trial, the participant was positioned four meters from the projection screen, holding a bespoke response device in each hand (see Figure 2a). The device was equipped with two response buttons: one to record the participant's online expectations throughout

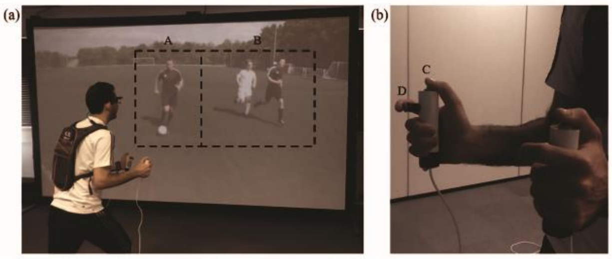

Figure 2. Panel a: Experimental setup. A depiction of the experimental task with areas of interest superimposed (A = player in possession; B = players off the ball; Note: These markings were not visible to participants). Panel b: Close-up of handheld devices with response buttons (C = online expectations; D = final prediction). See the online article for the color version of this figure.

the trials and one to record his final prediction (see Figure 2b). Participants were instructed to indicate their expectations as soon as they started to feel that one direction was more likely than the other; they were also told that they could change their expectations throughout the trial. Participants were instructed to execute their final prediction as soon as they were certain enough to carry out an action based on their prediction; they were told that they could not change this response. The response time for their final prediction was displayed on-screen after each trial. Because the sequence was occluded 120 ms after the player in possession's final action, the participant was able to see whether his response was correct or incorrect. Participants were free to move as they preferred during the task performance to maximize the real-world representativeness of the task (cf. Roca et al., 2011).

Procedure

Prior to testing, participants were given an overview of the experimental protocol and were presented with two blocks of six trials to familiarize themselves with the experimental setup and the response requirements. They were then fitted with a lapel microphone and a body-pack transmitter that was wirelessly connected to a compact diversity receiver (ew112-p G3; Sennheiser, Wedemark, Germany) and a recording device (Zoom H5; Zoom Corporation, Tokyo, Japan), so that self-report data could be recorded. Eye-tracking glasses (Applied Science Laboratories, Bedford, MA) were subsequently fitted onto the participants' heads. The glasses were connected to a recording device in a small backpack that was worn by participants. The eye-tracking system was calibrated using a 9-point grid that covered the entire display. Calibration was checked between conditions, and recalibration was performed where necessary.

After the calibration of the eye-tracking system, the 48 test trials were presented under two informational conditions (i.e., 96 trials in total). Each condition of 48 trials was divided into six blocks, and each block comprised eight trials. In one condition, information about the player in possession's action tendencies (contextual priors; dribble = 67%, pass = 33%) was explicitly announced prior to each block, both verbally and on-screen. In the other condition, no contextual priors were explicitly provided; however, the proportion of actions was the same as in the condition with explicit contextual priors (i.e., dribble = 67%, pass = 33%). The order in which conditions were presented was randomized and counterbalanced across skill groups (i.e., half of the expert group and half of the novice group began with the condition containing explicit contextual priors, whereas the other half began without priors). To eliminate the influence of trial-specific characteristics, we presented the same 48 trials in both informational conditions. However, to avoid any potential familiarity between conditions, the trial order in each condition was randomized. Upon completion of each block, the participant was asked to indicate his perceived level of cognitive effort when completing the trials in the preceding block, using the Rating Scale Mental Effort (RSME; Zijlstra, 1993). To minimize the influence of the experimental manipulations on data collected in the subsequent condition, we had participants complete a *washout* condition comprising three blocks of six trials between each test condition. Prior to each of the three washout blocks, novel information about the opponent's action tendencies was explicitly provided (dribble = 40%, pass = 60%; dribble = 60%, pass = 40%; dribble = 50%, pass = 50%, in this order). This information corresponded to the proportion of dribbles and passes that the player in possession performed within each block of the washout condition. The entire test session was completed in 60 min.

Dependent Measures

Visual dwell time. We characterized the overt allocation of visual attention as the relative distribution of visual dwell time across two interest areas: the player in possession of the ball and the players off the ball (see Figure 2). Dwell-time distributions have previously been used as an index of visual attentional allocation (e.g., Bayliss et al., 2013; Cavanagh, Wiecki, Kochar, & Frank, 2014; Fox, Russo, Bowles, & Dutton, 2001). The three most discriminating congruent and incongruent trials based on combined within-group differences for efficiency scores, making it six trials for each condition and participant (i.e., 372 trials in total), were subjected to gaze analysis.[1] We selected only the most discriminating trials based on performance outcomes to provide the most sensitive measure of how well the variable of interest (in our study: visual dwell time) predicts the performance measure of interest (in our study: anticipation efficiency; Ericsson & Smith, 1991). This is a well-established approach when assessing the perceptual or cognitive mechanisms behind certain performance effects (e.g., Martins, Garganta, Oliveira, & Casanova, 2014; Murphy et al., 2016; Roca et al., 2013). The data were analyzed frame-by-frame using Windows Media Player Version 12 (Microsoft Corporation, WA). Because we predicted that attentional allocation would evolve as the player in possession's kinematics became more informative, visual dwell time was analyzed for each trial in its entirety (0–4,960 ms), as well as for the first (0–2,479 ms) and second (2,480–4,960 ms) halves of the trial, separately. Visual dwell time outside the classified areas of interest (<0.6%) and missing data due to equipment failure (<1.1%) or trials in which invalid button presses were made (<2.5%) were excluded from the gaze analysis. Also, trials for which more than 20% of the data were missing (<2.2%) were excluded. N. Viktor Gredin analyzed all trials. A random sample containing 10% of all data was reanalyzed to obtain intra- (96%) and inter- (92%) observer reliability. In the latter instance, the data were recoded by an independent researcher.

Expectation accuracy. The accuracy of online expectations was expressed as the correspondence of participants' button presses to the direction of the final action. All expectation responses that the participants made over the course of a trial were included in the average accuracy score that was calculated for each informational condition. Because we predicted a congruence effect for expectation accuracy, both combined and separate analyses of congruent and incongruent trials were carried out. Trials for which response times differed by more than three standard deviations (<0.3%) from the participants' mean response times were deemed invalid button presses and were excluded from the analysis. In the condition without explicit contextual priors, the average accuracy score from the first three blocks was compared to the average score

[1] Gaze data from the trials chosen for analysis may not be representative of all trials (see the Discussion section for further comments on this).

from the final three blocks, to check whether information about the opponent's action tendencies was learned over time, according to the opponent's preceding actions.

Anticipation efficiency. To account for inevitable speed–accuracy trade-off, we expressed anticipatory performance as an efficiency score for each informational condition (cf. Bishop, Kuhn, & Maton, 2014). The efficiency score was calculated by multiplying the mean response time by the proportion of inaccurate trials for participants' final predictions; lower efficiency scores indicated superior anticipatory efficiency. Because we predicted a congruence effect for anticipation efficiency, both combined and separate analyses of congruent and incongruent trials were carried out. Responses executed after video occlusion (i.e., 120 ms after foot−ball contact) were recorded as inaccurate because too little time would have been afforded for participants to carry out a successful defensive action in response to the attack. Trials for which response times differed by more than three standard deviations from participants' mean response time (<1.2%) were deemed invalid button presses and were excluded from the analysis. In the condition without explicit contextual priors, the average efficiency score from the first three blocks was compared to the average score from the final three blocks, to check whether information about the opponent's action tendencies was learned over time, according to the opponent's preceding actions.

Cognitive effort. Perceived levels of cognitive effort were expressed by the RSME ratings. The scale ranges from 0 to 150 and contains nine descriptors (e.g., 2 = *absolutely no effort,* 58 = *rather much effort,* 113 = *extreme effort*). The RSME has been successfully used to assess levels of cognitive effort across various informational conditions (Cocks, Jackson, Bishop, & Williams, 2016).

Statistical Analysis

Descriptive statistics are reported as means and standard deviations. Magnitudes of observed effects are reported as standardized units (*d*), and uncertainties in true effects as 90% confidence limits. The between-groups effect in each informational condition was assessed by dividing the mean difference between the groups by the pooled standard deviation. The within-group effect between the condition without explicit contextual priors and the condition with priors was assessed by dividing the mean difference between the conditions by the standard deviation from the condition without explicit priors (cf. Cumming, 2012). The observed effect was interpreted against the following scale: $0.2 > |d|$, trivial; $0.2 \leq |d| < 0.5$, small; $0.5 \leq |d| < 0.8$, moderate; $0.8 < |d|$, large (Cohen, 1988). Cohen's standardized unit for the smallest substantial effect (0.2) was used as a threshold value when estimating the uncertainty in the true effect to have the same sign as does the observed effect. The following scale was used to convert the quantitative chances to qualitative descriptors: 25%–75%, possible; 75%–95%, likely; 95%–99.5%, very likely (Hopkins, 2002). If the lower and upper bounds of the confidence interval exceeded the thresholds for the smallest substantial negative and positive effect, respectively, then the effect was deemed unclear. All other effects were reported as the magnitude of the observed value and were evaluated probabilistically as described earlier. We chose against using traditional null-hypothesis significance testing (Neyman & Pearson, 1933) in favor of magnitude-based inference (Batterham & Hopkins, 2006). The latter approach was chosen because it is more informative to report magnitude of observed effects and precision of estimates than to report whether observed effects are statistically significant according to a specified alpha level (e.g., $p < .05$; Cumming, 2014; Wilkinson, 2014).

Results

Figure 3 shows the within-group effects of the explicit provision of contextual priors on our main dependent measures.

Visual Dwell Time

The group means and difference between expert and novice players in visual dwell time for each informational condition are presented in Table 1. As shown in Figure 3, experts decreased the time they spent looking at the player in possession of the ball ($d = -0.43 \pm 0.28$) and increased the time spent looking at the players off the ball ($d = 0.48 \pm 0.27$) when contextual priors were explicitly provided, relative to when they were not. Separate analyses of the first and second half of a trial showed that these differences emerged over the first half of the trial ($d = -0.42 \pm 0.27$ and $d = 0.45 \pm 0.25$, respectively), whereas no clear effects were found over the second half of the trial. The explicit provision of contextual priors had no clear effects on gaze behaviors in the novice group.

Expectation Accuracy

Group means and the difference between groups in expectation accuracy for each informational condition are presented in Table 2. The expert players increased their accuracy when contextual priors were explicitly provided, compared to when they were not ($d = 1.01 \pm 0.50$). No clear effect of the provision of contextual priors on accuracy for the novice players was reported. Figure 3 shows that for expert players, accuracy increased during congruent trials ($d = 0.93 \pm 0.52$) and decreased during incongruent trials ($d = -0.73 \pm 0.58$) when contextual priors were explicitly provided, compared to when they were not. The provision of contextual priors had no clear effects on novices during either congruent or incongruent trials. No clear effects were obtained, for experts or novices, when the average accuracy score for the initial three blocks in the condition without explicit contextual priors was compared to the average score for the final three blocks in the same condition.

Anticipation Efficiency

The descriptive statistics for response times and accuracy scores that were used to calculate the efficiency scores are shown in Table 3. As shown in Figure 4, when compared to their less skilled counterparts, the expert group's efficiency scores were lower (i.e., they were more efficient) both without (overall, $d = -1.01 \pm 0.60$; congruent, $d = -0.63 \pm 0.60$; incongruent, $d = -0.51 \pm 0.60$) and with (overall, $d = -0.71 \pm 0.59$; congruent, $d = -0.39 \pm 0.60$; incongruent, $d = -0.77 \pm 0.59$) explicit contextual priors. Both experts and novices improved their overall efficiency when contextual priors were provided, compared to when they were not ($d = -0.33 \pm 0.45$ and $d = -0.45 \pm 0.54$, respectively). As shown in Figure 3, explicit contextual priors exerted beneficial

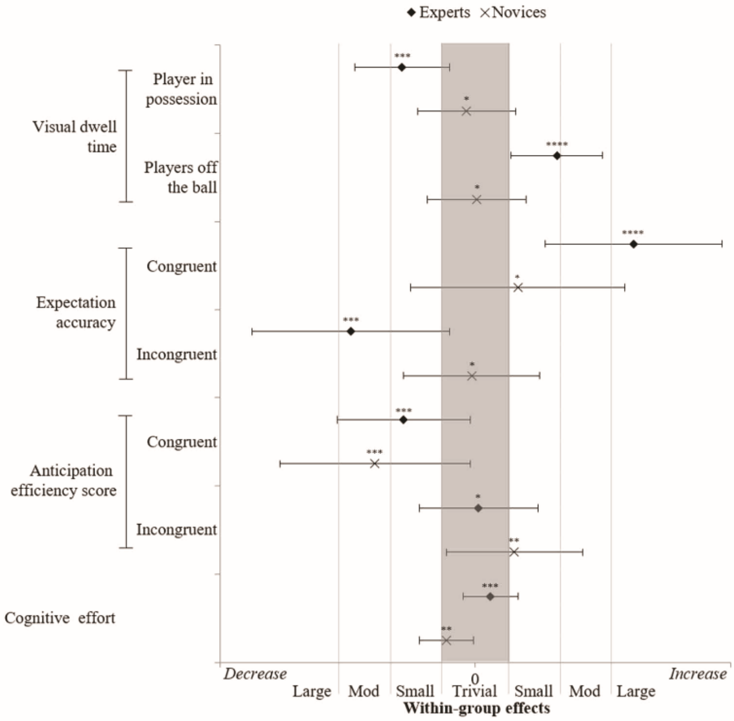

Figure 3. Within-group effects of explicit contextual priors (with explicit contextual priors vs. without explicit contextual priors). Standardized effects and 90% confidence limits for the effects of explicit contextual priors within each group, as well as inferences of observed and true effects within groups, for the main dependent measures. The effects represent the increase or decrease in scores for when contextual priors where explicitly provided, relative to when no explicit contextual priors were provided (note: Lower anticipation efficiency scores indicate superior efficiency). Inference of observed effect: $0.2 > |d|$, trivial; $0.2 \le |d| < 0.5$, small; $0.5 \le |d| < 0.8$, moderate; $0.8 < |d|$, large. Inference of uncertainty in true effect: * unclear, ** possibly (25%–75%), *** likely (75%–95%), **** very likely (95%–99.5%).

effects on congruent trials for both experts ($d = -0.42 \pm 0.39$) and novices ($d = -0.59 \pm 0.56$). However, on incongruent trials contextual priors yielded clear detrimental effects for novice ($d = 0.23 \pm 0.40$) but not expert players. No clear effects were obtained, for experts or novices, when the average efficiency score for the initial three blocks in the condition without explicit contextual priors was compared to the average score for the final three blocks in the same condition.

Cognitive Effort

The ratings of perceived levels of cognitive effort did not reveal any clear differences between experts and novices, either without ($M = 68$, $SD = 21$, and $M = 73$, $SD = 18$, respectively) or with ($M = 70$, $SD = 25$, and $M = 69$, $SD = 19$, respectively) explicit priors. The provision of contextual priors had no substantial effects on either expert ($d = 0.09 \pm 0.16$) or novice ($d = -0.17 \pm 0.16$) players (see Figure 3).

Discussion

We examined the ability of expert and novice soccer players to integrate explicit contextual priors pertaining to an opponent's action tendencies with current environmental information, such as opponent kinematics, when anticipating the opponent's next action. We used visual dwell time as a process measure of their acquisition of current environmental information. Furthermore, we captured the accuracy of their online expectations and assessed the efficiency of the final anticipatory judgments. We predicted that the players would strive to reduce the joint uncertainty associated with their final judgments by adopting a Bayesian strategy for integration of contextual priors and current environmental infor-

Table 1
Visual Dwell Time (%) on the PiP and the PoB, as well as Inference of Between-Groups Effects

Variable	Without explicit contextual priors			With explicit contextual priors		
	Experts	Novices	Δ (expert−novice)	Experts	Novices	Δ (expert−novice)
PiP						
Full trial[a]	69 ± 19	66 ± 18	Trivial*	61 ± 20	65 ± 15	Small (−)*
First trial half[b]	62 ± 24	57 ± 22	Small (+)*	51 ± 23	53 ± 17	Trivial*
Second trial half[c]	78 ± 16	75 ± 25	Trivial*	77 ± 18	78 ± 17	Trivial*
PoB						
Full trial[a]	28 ± 19	33 ± 19	Small (−)*	37 ± 19	34 ± 14	Small (+)*
First trial half[b]	35 ± 24	42 ± 22	Small (−)*	46 ± 22	44 ± 16	Trivial*
Second trial half[c]	20 ± 17	25 ± 25	Trivial*	22 ± 19	21 ± 17	Trivial*

Note. Data presented are means plus or minus standard deviations. PiP = player in possession; PoB = players off the ball. The full trial lasted 0–4,960 ms, the first trial half lasted 0–2,479 ms, and the second trial half lasted 2,480–4,960 ms. (−) represents a negative sign of effect, and (+) represents a positive sign of effect. Inference of observed effect: $0.2 > |d|$, trivial; $0.2 \leq |d| < 0.5$, small.
a = Full trial (0–4,960ms), b = First half of the trial (0–2,479 ms), c = Second half of the trial (2,480–4,960 ms). Inference of uncertainty in true effect: * unclear.

mation. In doing so, we predicted that the players would weight and combine available sources of information on the basis of their relative uncertainty (Körding, 2007). Furthermore, we believed that the uncertainties associated with the various sources of information would be assessed given their relevance as well as the players' ability to infer this relevance. It was predicted that experts, more so than novices, would use the explicit contextual priors to guide the allocation of visual attention (cf. Torralba, 2003) and to shape online expectations (cf. Loffing et al., 2015). However, we predicted that experts would update these expectations as new environmental information entered the display (cf. Clark, 2013), resulting in superior anticipation efficiency when compared to novices.

In line with our predictions, the explicit provision of contextual priors guided the experts' visual attention toward more context-relevant environmental information. It is worth noting that this finding refers to analysis of the six most discriminating trials for each participant, according to the effect of explicit contextual priors on anticipation efficiency (cf. Ericsson & Smith, 1991; Martins et al., 2014; Murphy et al., 2016; Roca et al., 2013). Although comparing these gaze data to those from all trials would be interesting from a methodological perspective, this was beyond the scope of this study. The experts increased the time they spent looking at the players off the ball and decreased the time spent looking at the player in possession, relative to when no contextual priors were explicitly given; this effect was not found for novices. In the current study, the final positioning (left or right) of the opponent off the ball revealed information that enabled the participants to use the contextual priors more effectively (i.e., if the players off the ball were on the left side, 67% of the opponent in possession's final actions were to the right, and vice versa). This information could be confirmed early in the trial because the opponent off the ball made his direction change ~1.5 s after trial onset. This finding supports the notion that contextual priors induce a more top-down, context-driven selection of environmental information (Eberhardt et al., 2004; Torralba, 2003). Separate analyses revealed that the explicit contextual priors biased how experts allocated their visual attention over the first half of the trial only (i.e., the period during which the opponent off the ball changed direction). Over the latter half of the trial (i.e., closer to the point of action execution) the player in possession's kinematics became more revealing (cf. Farrow, Abernethy, & Jackson, 2005). This finding is in line with our prediction that the impact of explicit contextual priors would emerge predominantly over the first half of the trial, in which the direction change of the opponent off the ball occurred and the kinematic information from the opponent in possession was not relevant to the final action. The progressive unfolding of relevant environmental information complements the results of previous research that has shown that the effect of contextual priors is mediated by the relative uncertainty associated with confirmatory or conflicting environmental information (Brouwer & Knill, 2009; Miyazaki et al., 2005; Tassinari et

Table 2
Expectation Accuracy (%) for Overall, Congruent, and Incongruent Trials, as well as Inference of Between-Groups Effects

Variable	Without explicit contextual priors			With explicit contextual priors		
	Experts	Novices	Δ (expert−novice)	Experts	Novices	Δ (expert−novice)
Overall	42 ± 9	47 ± 8	Moderate (−)***	51 ± 10	50 ± 13	Trivial*
Congruent	26 ± 20	39 ± 19	Moderate (−)***	45 ± 26	44 ± 30	Trivial*
Incongruent	71 ± 18	60 ± 24	Small (+)***	57 ± 28	60 ± 25	Trivial*

Note. Data presented are means plus or minus standard deviations. (−) represents negative sign of effect, and (+) represents positive sign of effect. Inference of observed effect: $0.2 > |d|$, trivial; $0.2 \leq |d| < 0.5$, small; $0.5 \leq |d| < 0.8$, moderate. Inference of uncertainty in true effect: * unclear; *** likely (75%–95%).

Table 3

Response Time (milliseconds) and Accuracy (%) of Final Predictions for Overall, Congruent, and Incongruent Trials

Variable	Without explicit contextual priors: Experts	Without explicit contextual priors: Novices	With explicit contextual priors: Experts	With explicit contextual priors: Novices
Response time				
Overall	4,437 ± 583	4,761 ± 210	4,303 ± 576	4,768 ± 198
Congruent	4,413 ± 577	4,735 ± 209	4,283 ± 562	4,745 ± 188
Incongruent	4,486 ± 598	4,812 ± 217	4,342 ± 611	4,816 ± 227
Accuracy				
Overall	54 ± 9	48 ± 9	57 ± 10	53 ± 10
Congruent	66 ± 14	61 ± 15	72 ± 10	70 ± 12
Incongruent	31 ± 20	23 ± 18	28 ± 20	18 ± 14

Note. Data presented are means plus or minus standard deviations.

al., 2006). Furthermore, the expertise effect revealed in our study provides novel evidence that this relative uncertainty is subject to the temporal relevance of available information as well as the individual's ability to infer this relevance.

As predicted, the expertise effect on visual attention was mirrored in the online expectations expressed by players. With explicit priors, experts enhanced their expectation accuracy when the oncoming opponent carried out the most likely action given his action tendencies (i.e., congruent trials). When the least likely action was performed by the opponent (i.e., incongruent trials), the provision of priors decreased the accuracy of online expectations. However, we did not find these biasing effects for online expectations in novices. These findings are consistent not only with our dwell time data but with the results of previously published research showing that experts are superior to novices at using prior contextual information (Farrow & Reid, 2012). It is worth noticing that the expert players in our study were biased by the opponent's action tendencies only when information about these tendencies was explicitly provided. This finding suggests that, in contrast to findings in previous research (Loffing et al., 2015; Mann et al., 2014), the players in our study were not able to utilize contextual information derived from task experience alone (i.e., from the opponent's actions in preceding trials).

An effect was also found for the explicit provision of contextual priors, but not for task experience alone, on the players' efficiency when making their final judgments. In line with our predictions, the explicit provision of priors enhanced anticipation efficiency on congruent trials among both experts and novices. We argue that combining the contextual priors and confirmatory kinematic information resulted in lower informational uncertainty and, consequently, superior anticipatory judgment, compared to when no contextual priors were explicitly provided. For experts, these findings correspond with our findings for visual attention and online expectations, as well as results of previous published reports that have emphasized the beneficial impact of contextual priors (Brouwer & Knill, 2009; Loffing et al., 2015; Miyazaki et al., 2005; Tassinari et al., 2006). It is noteworthy that the enhanced efficiency demonstrated by novices was not accompanied by any biases in their allocation of visual attention or online expectations. This finding suggests that novices ultimately used the contextual priors to guide their anticipatory judgments but did not integrate them with current environmental information to form and update their in-task expectations. As predicted by a Bayesian framework for probabilistic inference, novices employed a less optimal combination of available informational variables, when compared to experts, resulting in inferior final anticipatory judgment efficiency for congruent trials.

We predicted that, for incongruent trials, the explicit priors would impair the efficiency of the final anticipatory judgment in experts and, to a greater extent, in novices. However, impaired performance on incongruent trials was evidenced only in novices, which contradicts the expertise effect reported by Loffing and colleagues (2015). In the light of Bayesian theory, we speculate that the contrasting expertise effects could be because Loffing and colleagues used a temporal occlusion paradigm. We argue that the

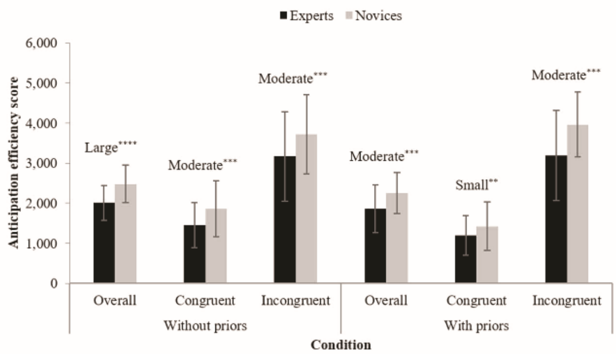

Figure 4. Between-groups effects for anticipation efficiency. Group means and standard deviations for efficiency scores in each informational condition, as well as inferences of observed and true effects between groups (note: Lower scores indicate superior anticipatory efficiency). Inference of observed effect: $0.2 \leq |d| < 0.5$, small; $0.5 \leq |d| < 0.8$, moderate; $0.8 < |d|$, large. Inference of uncertainty in true effect: ** possibly (25%–75%), *** likely (75%–95%), **** very likely (95%–99.5%).

experts in our study used their superior ability to interpret opponents' kinematics in the final stages of the action (cf. Krupinski, 2000; Savelsbergh et al., 2002; Underwood, 2007) to update their prior expectations. In contrast, important kinematic information may have been occluded in the study by Loffing and colleagues. This suggestion is supported by the notion that contextual priors have a greater impact on soccer goalkeepers, who spend less time attending to the kicker's kinematics (Navia et al., 2013).

These findings suggest that the impact of contextual priors is governed by both the availability of relevant environmental information and the performer's processing priorities of the information available in the environment. In support of Bayesian theory, we argue that, compared to novices, the expert players used a more optimal weighing of contextual priors and environmental information, resulting in superior efficiency of their final anticipatory judgment on incongruent trials. These findings may have practical implications, because recent advances in technology have enabled sophisticated analyses of forthcoming opponents' action tendencies−movement patterns; hence, the explicit provision of contextual priors has become a vital component of preparation in elite sport (Memmert, Lemmink, & Sampaio, 2017). Specifically, our study provides novel evidence that the impact of explicitly providing such information is subject to not only the availability of environmental information but also the athlete's ability to use this information.

In contrast to what we predicted, the use of priors did not engender increased levels of perceived cognitive effort for either experts or novices. This finding contradicts previous suggestions that remembering and applying prior probabilistic rules may induce greater cognitive demands (Green & Flowers, 2003). However, it is possible that the retrospective reports collected in our study did not accurately capture the fluctuation in demands over the course of a trial. The potential limitations of using retrospective subjective ratings as a measure of online cognitive effort suggest that researchers should explore this topic further using concurrent neuroscientific measures of cognitive effort (cf. Borghini, Astolfi, Vecchiato, Mattia, & Babiloni, 2014) and/or by comparing performances across conditions with varying cognitive demands (cf. Runswick, Roca, Williams, Bezodis, & North, 2017). An increased understanding of this phenomenon may have practical implications for performance under cognitively demanding conditions; for example, in the presence of a secondary task (Abernethy, Maxwell, Masters, Van Der Kamp, & Jackson, 2012).

In summary, our novel findings suggest that the explicit provision of contextual priors biases anticipatory judgments and shapes the underlying perceptual and cognitive strategies employed by individuals. As prescribed by a Bayesian framework for probabilistic inference, the impact of explicit contextual priors seems to alter as a function of the relative uncertainties associated with the available sources of information (Körding, 2007). The temporal effects, together with the expertise effects reported in this article, suggest that these uncertainties are governed by the temporal relevance of the information at hand as well as by the individual's ability to infer this relevance. It appears that experts integrate contextual priors with environmental information more effectively than do novices. This effect was highlighted in our data by the shifts in overt visual attention according to the prevailing contextual information (cf. Torralba, 2003) and by updating of expectations as new confirmatory or conflicting information emerged (cf. Clark, 2013). In keeping with Bayesian theory, this results in a more reliable joint estimate of future events and enables experts to anticipate with greater efficiency than do their novice counterparts (for Bayesian network modelling to classifying anticipation efficiency for experts and novices, see online supplemental materials). Our novel findings have implications for the assessment and enhancement of anticipation across a multitude of professional domains.

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Appendix 2: Research Ethical Approval Letter (Chapter 3)

College of Health and Life Sciences Research Ethics Committee (DLS)
Brunel University London
Kingston Lane
Uxbridge
UB8 3PH
United Kingdom

www.brunel.ac.uk

13 September 2016

LETTER OF APPROVAL

Applicant: Mr Viktor Gredin

Project Title: Probabilistic information in soccer

Reference: 3618-LR-Sep/2016- 4001-1

Dear Mr Viktor Gredin

The Research Ethics Committee has considered the above application recently submitted by you.

The Chair, acting under delegated authority has agreed that there is no objection on ethical grounds to the proposed study. Approval is given on the understanding that the conditions of approval set out below are followed:

- The agreed protocol must be followed. Any changes to the protocol will require prior approval from the Committee by way of an application for an amendment.

Please note that:

- Research Participant Information Sheets and (where relevant) flyers, posters, and consent forms should include a clear statement that research ethics approval has been obtained from the relevant Research Ethics Committee.
- The Research Participant Information Sheets should include a clear statement that queries should be directed, in the first instance, to the Supervisor (where relevant), or the researcher. Complaints, on the other hand, should be directed, in the first instance, to the Chair of the relevant Research Ethics Committee.
- Approval to proceed with the study is granted subject to receipt by the Committee of satisfactory responses to any conditions that may appear above, in addition to any subsequent changes to the protocol.
- The Research Ethics Committee reserves the right to sample and review documentation, including raw data, relevant to the study.
- You may not undertake any research activity if you are not a registered student of Brunel University or if you cease to become registered, including abeyance or temporary withdrawal. As a deregistered student you would not be insured to undertake research activity. Research activity includes the recruitment of participants, undertaking consent procedures and collection of data. Breach of this requirement constitutes research misconduct and is a disciplinary offence.

Professor Christina Victor

Chair

College of Health and Life Sciences Research Ethics Committee (DLS)
Brunel University London

Appendix 3: Research Ethical Approval Letter (Chapter 4)

College of Health and Life Sciences Research Ethics Committee (DLS)
Brunel University London
Kingston Lane
Uxbridge
UB8 3PH
United Kingdom

www.brunel.ac.uk

13 March 2018

LETTER OF APPROVAL

Applicant: Mr Viktor Gredin

Project Title: The use of prior and environmental information during action anticiaption in soccer

Reference: 10313-LR-Mar/2018- 12152-2

Dear Mr Viktor Gredin

The Research Ethics Committee has considered the above application recently submitted by you.

The Chair, acting under delegated authority has agreed that there is no objection on ethical grounds to the proposed study. Approval is given on the understanding that the conditions of approval set out below are followed:

- The agreed protocol must be followed. Any changes to the protocol will require prior approval from the Committee by way of an application for an amendment.

Please note that:

- Research Participant Information Sheets and (where relevant) flyers, posters, and consent forms should include a clear statement that research ethics approval has been obtained from the relevant Research Ethics Committee.
- The Research Participant Information Sheets should include a clear statement that queries should be directed, in the first instance, to the Supervisor (where relevant), or the researcher. Complaints, on the other hand, should be directed, in the first instance, to the Chair of the relevant Research Ethics Committee.
- Approval to proceed with the study is granted subject to receipt by the Committee of satisfactory responses to any conditions that may appear above, in addition to any subsequent changes to the protocol.
- The Research Ethics Committee reserves the right to sample and review documentation, including raw data, relevant to the study.
- You may not undertake any research activity if you are not a registered student of Brunel University or if you cease to become registered, including abeyance or temporary withdrawal. As a deregistered student you would not be insured to undertake research activity. Research activity includes the recruitment of participants, undertaking consent procedures and collection of data. Breach of this requirement constitutes research misconduct and is a disciplinary offence.

Professor Christina Victor

Chair

College of Health and Life Sciences Research Ethics Committee (DLS)
Brunel University London

Appendix 4: Research Ethical Approval Letter (Chapter 5)

College of Health and Life Sciences Research Ethics Committee (DLS)
Brunel University London
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24 October 2017

LETTER OF APPROVAL

Applicant: Mr Viktor Gredin

Project Title: Footballers' use of probabilistic information under low and high cognitive demands

Reference: 6563-A-Oct/2017- 8515-1

Dear Mr Viktor Gredin

The Research Ethics Committee has considered the above application recently submitted by you.

The Chair, acting under delegated authority has agreed that there is no objection on ethical grounds to the proposed study. Approval is given on the understanding that the conditions of approval set out below are followed:

- The agreed protocol must be followed. Any changes to the protocol will require prior approval from the Committee by way of an application for an amendment.

Please note that:

- Research Participant Information Sheets and (where relevant) flyers, posters, and consent forms should include a clear statement that research ethics approval has been obtained from the relevant Research Ethics Committee.
- The Research Participant Information Sheets should include a clear statement that queries should be directed, in the first instance, to the Supervisor (where relevant), or the researcher. Complaints, on the other hand, should be directed, in the first instance, to the Chair of the relevant Research Ethics Committee.
- Approval to proceed with the study is granted subject to receipt by the Committee of satisfactory responses to any conditions that may appear above, in addition to any subsequent changes to the protocol.
- The Research Ethics Committee reserves the right to sample and review documentation, including raw data, relevant to the study.
- You may not undertake any research activity if you are not a registered student of Brunel University or if you cease to become registered, including abeyance or temporary withdrawal. As a deregistered student you would not be insured to undertake research activity. Research activity includes the recruitment of participants, undertaking consent procedures and collection of data. Breach of this requirement constitutes research misconduct and is a disciplinary offence.

Professor Christina Victor

Chair

College of Health and Life Sciences Research Ethics Committee (DLS)
Brunel University London

Appendix 5: Research Ethical Approval Letter (Chapter 6 [CHLS])

College of Health and Life Sciences Research Ethics Committee (DLS)
Brunel University London
Kingston Lane
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19 April 2018

LETTER OF APPROVAL

Applicant: Mr Viktor Gredin

Project Title: The impact of outcome costs and rewards on action anticipation

Reference: 11291-LR-Apr/2018- 12523-3

Dear Mr Viktor Gredin

The Research Ethics Committee has considered the above application recently submitted by you.

The Chair, acting under delegated authority has agreed that there is no objection on ethical grounds to the proposed study. Approval is given on the understanding that the conditions of approval set out below are followed:

- The agreed protocol must be followed. Any changes to the protocol will require prior approval from the Committee by way of an application for an amendment.

Please note that:

- Research Participant Information Sheets and (where relevant) flyers, posters, and consent forms should include a clear statement that research ethics approval has been obtained from the relevant Research Ethics Committee.
- The Research Participant Information Sheets should include a clear statement that queries should be directed, in the first instance, to the Supervisor (where relevant), or the researcher. Complaints, on the other hand, should be directed, in the first instance, to the Chair of the relevant Research Ethics Committee.
- Approval to proceed with the study is granted subject to receipt by the Committee of satisfactory responses to any conditions that may appear above, in addition to any subsequent changes to the protocol.
- The Research Ethics Committee reserves the right to sample and review documentation, including raw data, relevant to the study.
- You may not undertake any research activity if you are not a registered student of Brunel University or if you cease to become registered, including abeyance or temporary withdrawal. As a deregistered student you would not be insured to undertake research activity. Research activity includes the recruitment of participants, undertaking consent procedures and collection of data. Breach of this requirement constitutes research misconduct and is a disciplinary offence.

Professor Christina Victor

Chair

College of Health and Life Sciences Research Ethics Committee (DLS)
Brunel University London

Appendix 6: Research Ethical Approval Letter (Chapter 6 [IRB])

INSTITUTIONAL REVIEW BOARD
THE UNIVERSITY OF UTAH
75 South 2000 East Salt Lake City, UT 84112 | 801.581.3655 | IRB@utah.edu

IRB: IRB_00111032

PI: Bradley Fawver

Title: The impact of outcome costs and rewards on the use of contextual priors during action anticipation in soccer

Date: 4/13/2018

The above-referenced protocol has received an IRB exemption determination and may begin the research procedures outlined in the University of Utah IRB application and supporting documents.

EXEMPTION DOCUMENTATION

Review Type: Exemption Review
Exemption Category(ies): Category 11
Exemption Date: 4/13/2018

Approval by the University of Utah IRB does not necessarily constitute authorization to initiate the conduct of this research. Investigators are responsible for ensuring that final approval is obtained from other applicable institutional officials, departments, or ancillary committees, as well as any external sites participating in research activities, such as schools and universities, businesses, hospitals, community organizations, etc. Please ensure documentation of such approval or permission is obtained and maintained in the research record.

Note the following delineation of categories:

- Categories 1-6: Federal Exemption Categories defined in 45 CFR 46.101(b)
- Categories 7-11: Non-Federal Exemption Categories defined in University of Utah IRB policy in Investigator Guidance Series, Exempt Research

You must adhere to all requirements for exemption described in University of Utah IRB policy in (Investigator Guidance Series, Exempt Research). This includes:

- All research involving human subjects must be approved or determined exempt by the IRB before the research is conducted.
- All research activities must be conducted in accordance with the Belmont Report and must adhere to principles of sound research design and ethics.
- Orderly accounting and monitoring of research activities must occur.

Ongoing Submissions for Exempt Projects

- **Continuing Review:** Since this determination is not an approval, the study does not expire or need continuing review. This determination of exemption from continuing IRB review only applies to the research study as submitted to the IRB. You must follow the protocol as proposed in this application
- **Amendment Applications:** Substantive changes to this project require an amendment application to the IRB to secure either approval or a determination of exemption. **Investigators should contact the IRB Office if there are questions about whether an amendment consists of substantive changes.** Substantive changes include, but are not limited to
    - Changes to study personnel (to secure Conflict of Interest review for all personnel on the study)
    - Changes that increase the risk to participants or change the risk:benefit ratio of the study
    - Changes that affect a participant's willingness to participate in the study
    - Changes to study procedures or study components that are not covered by the Exemption Category determined for this study (listed above)
    - Changes to the study sponsor
    - Changes to the targeted participant population
    - Changes to the stamped consent document(s)
- **Report Forms:** Exempt studies must adhere to the University of Utah IRB reporting requirements for unanticipated problems and deviations: http://irb.utah.edu/submit-application/forms/index.php
- **Final Project Reports for Study Closure:** Exempt studies must be closed with the IRB once the research activities are complete: http://irb.utah.edu/submit-application/final-project-reports.php

SUPPORTING DOCUMENTS

Informed Consent Document
Consent Document

Surveys, etc.
Demographics Form

Literature Cited/References
References

Click IRB_00111032 to view the application.

Please take a moment to complete our customer service survey. We appreciate your opinions and feedback.