Judgement utility modulates the use of explicit contextual priors and visual information during anticipation

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A B S T R A C T

Objectives: We examined the impact of judgement utility on the use of explicit contextual priors and visual information during action anticipation in soccer.
Design: We employed a repeated measures design, in which expert soccer players had to perform a video-based anticipation task under various conditions.
Methods: The task required the players to predict the direction (left or right) of an oncoming opponent's imminent actions. 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 (dribble = 70%; pass = 30%) were explicitly provided. In one of these experimental conditions, players were told that an incorrect 'right' response would result in conceding a goal, which created imbalanced judgement utility (left = high utility; right = low utility). In the third control condition, no explicit contextual priors or additional instructions were provided.
Results: The explicit provision of contextual priors changed players' processing priorities, biased their anticipatory judgements in accordance with the opponent's action tendencies, and enhanced anticipation performance. These effects were suppressed under conditions in which the explicit contextual priors were accompanied by imbalanced judgement utility. Under these conditions, the players were more concerned about the consequences of their judgements and were more inclined to opt for the direction with the higher utility.
Conclusions: It appears that judgement utility disrupts the integration of contextual priors and visual information, which results in decreased impact of explicit contextual priors during action anticipation.

1. Introduction

In dynamic and rapidly evolving environments, fast and accurate anticipation of an opponent's actions underpins expert performance (Williams, 2000). Researchers have tried to elucidate the processes by which athletes combine prior knowledge and beliefs relevant to the specific performance context (i.e., contextual priors) with evolving visual information during anticipation (see Cañal-Bruland & Mann, 2015; Williams & Jackson, 2018). It has been proposed that athletes may employ Bayesian reliability-based strategies to weigh up, and integrate, contextual priors with relevant visual information: the reliance on contextual priors and visual information is modulated by the comparative reliability of the information at hand, where more reliance is assigned to information of relatively higher certainty with regard to the to-be-anticipated event (Gredin, Bishop, Broadbent, Tucker, &

Williams, 2018). 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 potential costs and rewards associated with the consequences of one's predictions: high judgement utility is associated with high rewards (if accurate) and low costs (if inaccurate), and vice versa for low judgement utility. According to Bayesian theory, people attempt to maximise the probability of their judgements being accurate while simultaneously maximise the expected utility of their judgments (Geisler & Diehl, 2003). In the current study, we examined the impact of judgement utility on the integration of explicit contextual priors and visual information during anticipation in soccer.

It is well-established that expert athletes use advance visual information, such as opponent kinematics, to predict an opponent's next move (e.g., Farrow, Abernethy, & Jackson, 2005; Loffing & Hagemann,

2014; Wright, Bishop, Jackson, & Abernethy, 2013). However, in recent years, researchers have taken a broader focus when examining the nature of anticipation in sport, by exploring the importance of non-visual information, such as contextual priors (Broadbent, Gredin, Rye, Williams, & Bishop, 2018; Gray & Cañal-Bruland, 2018; Gredin et al., 2018; Navia, Van der Kamp, & Ruiz, 2013; Runswick et al., 2018a). 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). Gredin et al. (2018) recorded gaze patterns and anticipatory judgements while soccer players predicted an opponent's imminent actions with the ball in 2-versus-2 defensive soccer scenarios. The players performed the task both with and without explicitly provided contextual priors pertaining to the action tendencies of the attacker on the ball – specifically, whether he tended to dribble or pass the ball to a teammate. When given priors, the players allocated their visual attention toward the attacking teammate off the ball over the first half of each trial, as their determination of the teammate's run trajectory enabled them to inform their judgements according to the action tendencies of the attacker on the ball. Over the second half of each trial, closer to the key point of action, the players relied more on evolving kinematic information of the attacker on the ball to inform their judgements. The provision of explicit priors biased the players' judgements toward the most likely action, given the action tendencies, which resulted in enhanced task performance (see also Broadbent et al., 2018; Navia et al., 2013). Similarly, the beneficial performance effect of contextual priors was reported by Runswick et al. (2018a) using a task that required cricket batters to predict the location of forthcoming deliveries from bowlers. The batters exhibited superior anticipation when facing the same bowler six times in a row and when explicitly provided with information about the game state and field setting, compared to under conditions in which they faced six different bowlers and were not explicitly presented information about the game state and field setting. In the former condition, retrospective verbal reports demonstrated that the batters relied more on contextual priors to inform their judgements when compared to the latter condition.

In the quest to develop an overarching framework that might explain the processes by which athletes combine contextual priors and visual information during anticipation, Loffing and Cañal-Bruland (2017) suggested that Bayesian theory may provide a suitable framework to elucidate these processes. 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., higher certainty) than another, then the individual's joint estimate should be biased toward the 'more reliable' informational variable (Knill & Pouget, 2004). In line with the suggestion by Loffing and Cañal-Bruland (2017), Gredin et al. (2018) evaluated their findings using a Bayesian framework for probabilistic inference. In keeping with Bayesian theory, the authors proposed that players integrated explicit contextual priors and evolving visual information according to the comparative levels of reliability associated with the different sources of information (see Vilares & Körding, 2011). That is, the players were more dependent on priors over the first half of each trial where the reliability of kinematic information was low, and vice versa (see also Gray & Cañal-Bruland, 2018).

A fundamental aspect of Bayesian theory is that our ultimate judgements are affected by both the reliability of available information and the potential costs and rewards associated with inaccurate and accurate judgements. Put in Bayesian terms, the weighted average of the reliability conveyed by prior and current sources of information is convolved with the utility values assigned to possible judgements (Geisler

& Diehl, 2003). The biasing effect of judgement utility reflects not only to our desire to gain rewards and avoid costs, but also our tendency to use current information to confirm the viability of the high-utility option. As such, we tend to overestimate the likelihood of the outcome in accordance with its utility (see DeKay, Patiño-Echeverri, & Fischbeck, 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 had a cyst. It was proposed that physicians overestimated the chances of a tumour due to its more severe consequences, relative to a cyst. In other words, a tumour diagnosis would yield greater rewards (if correct) and lower costs (if incorrect) than would diagnosing a cyst. In line with this finding, Cañal-Bruland, Filius, and Oudejans (2015) reported 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 handle the high speed of a fastball and, due to the slower nature of change-ups, to adapt their swing if confronted with this latter pitch type. If expecting a change-up, on the other hand, batters would not be able 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 anticipation in sport. However, the manner in which judgement utility modulates the impact of contextual priors and processing priorities during anticipation has yet to be examined empirically. Greater awareness of the effects of judgement utility on athletes' use of contextual priors will strengthen our understanding of action anticipation processes in sport – which will ultimately enhance coaches' and performance analysts' ability to maximise the effectiveness of explicit contextual priors (see Cañal-Bruland & Mann, 2015).

In the current study, we examined the impact of judgement utility on the integration of explicit contextual priors and visual information as expert soccer players anticipated an oncoming opponent's imminent actions. We employed the same task as used by Gredin et al. (2018): 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 the attacker on the ball's (termed 'the opponent' from hereon) action at the end of each sequence. In addition to conditions with and without explicitly provided contextual priors pertaining to the opponent's action tendencies (dribble = 70%; pass = 30%), an additional condition was added, in which contextual priors were explicitly provided *and* judgement utility was explicitly manipulated. Judgement utility was manipulated by telling the players that an incorrect 'right' response would result in conceding a goal, which created imbalanced judgement utility (left = high utility; right = low utility). We recorded anticipation judgements and collected retrospective verbal reports of the thoughts the players engaged in when solving the task.

We predicted that the explicit provision of contextual priors would bias anticipatory judgements toward the most likely action given the opponent's action tendencies (i.e., dribble) and consequently enhance their anticipation performance (Broadbent et al., 2018; Gredin et al., 2018). Furthermore, we predicted that the explicit provision of contextual priors would result in players engaging in more thoughts related to the positioning of the attacker off the ball (see the Method section for detailed explanation) and the opponent's action tendencies, whereas fewer thoughts would be related to the opponent's kinematics (cf., Runswick et al., 2018a). However, in keeping with Bayesian theory (see Geisler & Diehl, 2003), we predicted that these effects would be suppressed when the priors were accompanied with manipulated judgement utility, as players would be more inclined to opt for the direction associated with the higher utility value (i.e., left). In the condition where judgement utility was manipulated, it was hypothesised that the players would engage in more thoughts related to the costs and/or rewards that their responses could bring about. Based on Bayesian theories of weighted integration of information, we predicted that this would result in fewer thoughts related to the opponent's action

tendencies and relevant visual information.

2. Methods

2.1. Participants

A total of 18 (10 male and 8 female) expert soccer players (M_{age} = 23 years, SD = 3) participated. On average, the players had 14 years (SD = 2) of competitive experience in soccer at university or semi-professional level. At the time of the study, they participated in an average of 9 h (SD = 4) of soccer practice or match play per week. 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 performance effects (i.e., chances of the true effect to be substantially positive and negative < 5%; Batterham & Hopkins, 2006; see the Data Analysis section for further details). We used data from the study by Gredin et al. (2018) to calculate the minimum required sample size (n = 12; Hopkins, Marshall, Batterham, & Hanin, 2009). The study was approved by the Research Ethics Committee of the lead institution and conformed to the recommendations of the Declaration of Helsinki. All participants gave their written informed consent before taking part.

2.2. Test stimuli

The test stimuli comprised 30 video sequences of 2-versus-2 counter attacking scenarios in soccer, viewed from the perspective of one of the defenders. The test stimuli were filmed on an artificial turf soccer pitch using a high-definition digital video camera (Canon XF100, Tokyo, Japan) with a wide-angle converter lens (Canon WD-H72 0.8x, Tokyo, Japan). The camera was attached to a moving trolley, at a height of 1.7 m, to replicate the perspective of a central defender moving backwards. The final test footage was edited using Pinnacle Studio software (v15; Pinnacle, Ottawa, Canada). In total, 130 video simulations were created, but only clips that were independently selected by two qualified soccer coaches (UEFA A Licence holders), based on their representativeness of actual game play, were included in the final test footage of 30 clips.

In each sequence, there was one attacking player in possession of the ball ('the opponent'), a second attacker off the ball, and one marking defender who was following the second attacker throughout the sequence (see Figure 1). The videos were projected onto a 3.3 × 1.9 m projection screen using an Optoma HD20 DLP projector (Optoma, New Taipei City, Taiwan). The participant viewed the scenarios from a first-person perspective, as if they were the second defender. At the start of the sequence, the opponent was positioned approximately 7 m in front of the participant, 10 m to the right of the centre of the pitch, and 3 m inside the defensive half. The attacker off the ball and the second defender started approximately 3 m behind, either on the left, or the right, side of the opponent. When the sequence started to unfold, 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. The sequences lasted for 5 s and, at the end of each sequence, the opponent could either pass the ball to his teammate who was positioned either to the left or right of the opponent (30% of trials) or dribble the ball in the opposite direction of the teammate (70% of trials).

2.3. Task design

The participant was required to predict the direction (left or right) of the ball from the opponent's final action. At the start of each trial, the participant was standing 3.5 m in front of the projection screen holding a response device in each hand − one for 'left' responses and one for 'right' responses. The participant was instructed that they should 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 with regard to their response time and accuracy was displayed on-screen. Feedback for response time and accuracy was given as pilot testing suggested that receiving this information after each trial motivated the participant to stay engaged with the test task throughout the test session. A full 5-s trial was occluded 120 m s 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. Since players in a soccer match are normally aware of the position of the ball and other players each trial started with a frozen frame for 1 s to allow the participant to detect this information. During the course of a trial, the participant was free to move as preferred in order to maximise the real-world representativeness of the task (cf. Gredin et al., 2018).

2.4. Procedure

Before testing, the participant undertook 25–40 min of training in how to provide retrospective think-aloud reports. This training consisted of instructions on how to report thoughts retrospectively, including practice on a number of generic tasks. The participant was given feedback on their verbal reports, along with good and bad examples for these practice tasks (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. The aim of the verbal report training was to ensure that the participant learned how to verbalise only the thoughts that they used during the preceding task performance and to report them as they were naturally experienced during performance. This procedure is important to follow, as elaborating or providing commentary on the reported thoughts, or reporting thoughts that were not used during task performance may influence performance and violate the natural cognitive processes that occur during the task (Ericsson & Simon, 1980). 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 the 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 (*Control*), the participant performed the task without any additional information. In one of the experimental conditions (*EXP*), the participant performed the same task, but before 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%). Due to the nature of the task, the positioning of the attacker off the ball revealed information that enabled the participant to use information about the opponent's action tendencies (i.e., if the attacker off the ball was on the left, 70% of the opponent's final actions were to the right, and vice versa). This meant that the participant had to incorporate the explicit contextual priors (i.e., the opponent's action tendencies) with evolving visual information (i.e., the positioning of the attacker off the ball) in order to use the priors to inform their judgement. In complex and highly dynamic performance environments, such as in soccer, this interdependency between contextual priors and visual information may be an important component when seeking to elucidate the integration of different sources of information during anticipation (Gredin et al., 2018).

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
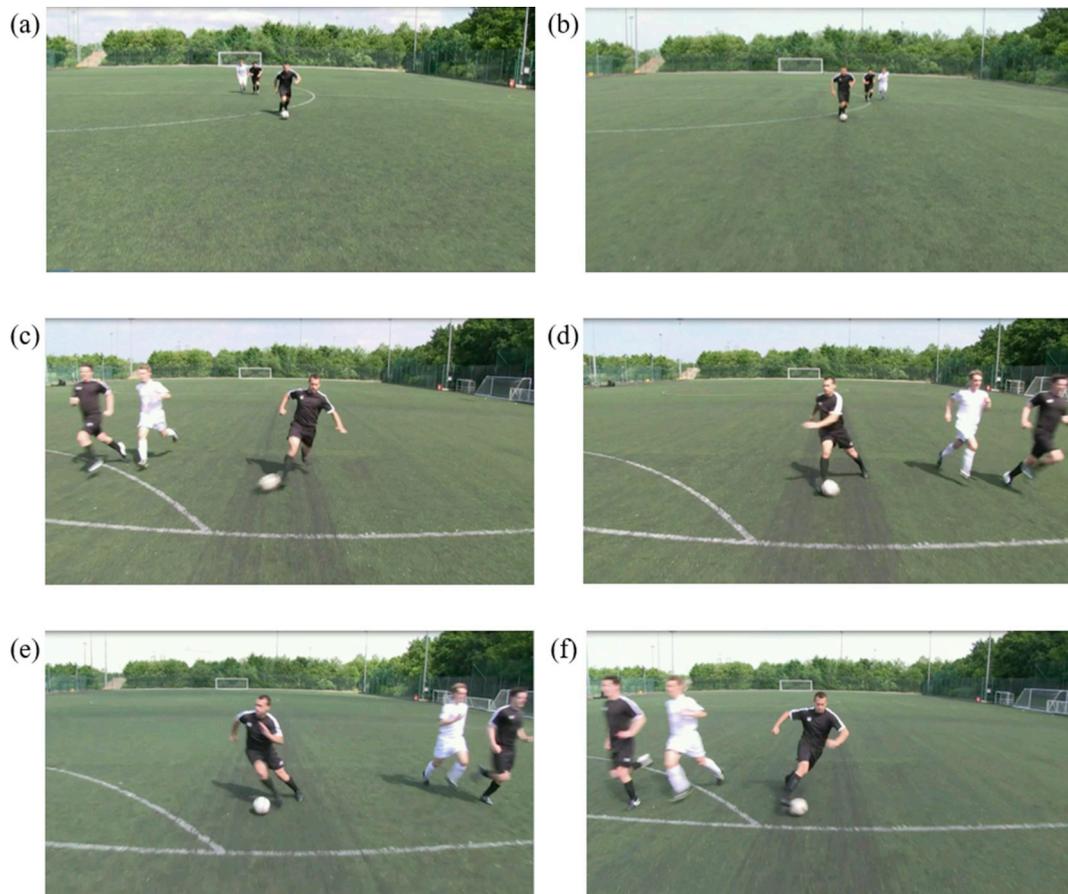
Figure 1. Test Stimuli. The two different positions that the attacker off the ball and the defender could have at the start of each sequence: to the left (a) or the right (b) side of the opponent. The four different actions that the opponent could carry out at the end of each sequence: pass left (c), pass right (d), dribble left (e), and dribble right (f).

incorrect (i.e., responded 'right') when the opponent passed or dribbled the ball toward the left, their team would concede a goal. 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 (i.e., to the participant's left in the present task) is more frequently associated with positive attacking outcomes than possession in a wider position (i.e., to the participant's right; Brooks, Kerr, & Guttag, 2016). The participant received this instruction before 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. 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 across all three conditions. Furthermore, these actions were equally distributed across left and right outcome directions. The order in which the conditions were presented was randomised and counterbalanced across participants, which is a commonly used design in order to mitigate potential learning and carryover effects across various experimental conditions in sport (e.g., Gray, 2009; Jackson, Ashford, & Norsworthy, 2006; Runswick, Roca, Williams, Bezodis, & North, 2017). To further avoid any potential familiarity between conditions, the trial order in each condition was randomised (cf. Gredin et al., 2018). Response time and accuracy were recorded for each trial and verbal reports of thoughts were collected after six trials in each condition (cf.

Runswick et al., 2018a). 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. The whole test session was completed within 90 min.

2.5. Dependent measures

Anticipatory judgements. To ascertain whether any systematic speed–accuracy trade-off effects were evident in the response data, Pearson correlations between response time and accuracy were determined for each condition. A positive correlation between the two variables was found in each of the three conditions (Control, $r = 0.59 \pm 0.28$ [90% CI]; EXP, $r = .66 \pm 0.24$; EXP[JU], $r = 0.68) \pm 0.23$). To account for this speed-accuracy trade off, anticipation performance was expressed as an *anticipation efficiency score*, which was calculated by multiplying the average response time by the proportion of inaccurate responses in each condition (note: lower efficiency score indicates superior anticipation performance; cf. Gredin et al., 2018). In addition to the anticipation efficiency score, anticipation performance was expressed by the change in response accuracy between each condition, where the change in response time was used as a covariate in order to account for the covariation in the speed and accuracy measures (cf. Abernethy, Schorer, Jackson, & Hagemann, 2012). As we predicted that explicit contextual priors would bias the players' judgements toward the most likely action, given the opponent's

action tendencies, we calculated the proportion of 'dribble' responses in each condition (note: a 'dribble' response corresponded to when the participant responded 'right' and the attacker off the ball was on the left side of the opponent *or* when the participant responded 'left' and the attacker off the ball was on the right side of the opponent). As we predicted that judgement utility would bias the players' judgement toward the direction with the comparatively higher utility, the proportion of 'left' responses in each condition was assessed.

Verbal reports. 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, Ford, McRobert, & Williams, 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 of 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 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 participants failing to follow the procedure required for providing retrospective think-aloud reports (see Eccles, 2012). Once statements within each eligible report had been categorised, the proportion of reports in each condition that contained statements of each category was assessed (note: each report could contain references to multiple sources of information; cf. Murphy et al., 2016).

2.6. 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. The effects were standardised by dividing the mean difference between conditions by the combined *SD* 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; Cumming, 2012). 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, meaning that there is ≥ 5% that the true effect could be substantially negative and ≥5% that it could be substantially positive, then the effect was deemed unclear. All other effects were deemed clear and evaluated as per the description above (Batterham & Hopkins, 2006). The confidence level of the CIs was not adjusted for multiple comparisons (Hopkins, Marchall, Batterham, & Hanin, 2009; Perneger, 1998; Rothman, 1990). Due to the low number of participants making references to the sources of non-visual information in their verbal reports, leading to high variability across participants and skewed data, inferential analyses were not conducted on the verbal reports of action tendencies and judgement utility. For these reports, descriptive statistics, including the number of participants referring to each information category, are presented.

3. Results

3.1. Anticipatory judgements

Table 1 shows the descriptive statistics for the response time and

Table 1
Descriptive statistics (M ± SD) for the response time (ms) and accuracy (%) in each condition.

|	Control	EXP	EXP[JU]
Response time	4416 ± 518	4316 ± 756	4405 ± 453
Response accuracy	63 ± 13	67 ± 10	65 ± 11

accuracy scores in each condition[1],[2]. As shown in Figure 2a, the participants exhibited superior performance, manifested in a lower anticipation efficiency score, in EXP than in Control ($d = 0.54 \pm 0.35$) and EXP[JU] ($d = 0.43 \pm 0.35$), whereas no substantial effect was obtained when the anticipation efficiency score in Control was compared to that in EXP[JU] ($d = 0.14 \pm 0.34$). The analysis of the adjusted effects for response accuracy between conditions revealed that response accuracy was higher in EXP than in Control ($d = 0.35 \pm 0.29$) and EXP[JU] ($d = 0.25 \pm 0.30$), whereas no substantial effect was found between Control and EXP[JU] ($d = 0.12 \pm 0.27$; note: changes in response time were included as a covariate in these analyses). The proportion of trials in which the participants predicted that the opponent would dribble was higher in EXP than in Control ($d = 0.66 \pm 0.47$) and EXP[JU] ($d = 0.89 \pm 0.46$), whereas no clear effect was found when the proportion of 'dribble' responses in Control was compared to that in EXP[JU] (see Figure 2a). Figure 2c shows that the proportion of trials where the participants predicted that the opponent would dribble or pass the ball toward the left was higher in Control than in EXP ($d = 0.33 \pm 0.42$) and higher in EXP[JU], both compared to Control ($d = 0.65 \pm 0.44$) and compared to EXP ($d = 1.03 \pm 0.47$). Unstandardised effects for anticipation efficiency, percentage 'dribble' responses, and percentage 'left' responses across conditions are presented in Table 2.

3.2. Verbal reports

The percentage of verbal reports referring to each category of visual information in each condition is presented in Figure 3. The participants reported a higher proportion of statements referring to the positioning of the attacker off the ball in EXP than in Control ($d = 0.37 \pm 0.34$) and EXP[JU] ($d = 0.22 \pm 0.39$), whereas no substantial difference was found between Control and EXP[JU] ($d = 0.12 \pm 0.28$). The percentage of statements referring to the kinematic information of the opponent was higher in Control than in EXP ($d = 0.59 \pm 0.27$) and EXP[JU] ($d = 1.03 \pm 0.43$), and higher in EXP than in EXP[JU] ($d = 0.47 \pm 0.27$). Regarding other sources of visual information, the participants reported a higher proportion of statements within this category in Control than in EXP ($d = 0.32 \pm 0.37$) and EXP[JU] ($d = 0.40 \pm 0.27$), while no clear difference was obtained between EXP and EXP[JU]. Unstandardised effects for the percentage of verbal reports referring to each category of visual information across conditions are presented in Table 3. In reports containing statements referring to non-visual information, the proportion containing statements relating to the opponent's action tendencies were 1.1% (SD = 4.3) in Control, 32.2% (SD = 28.5) in EXP, and 22.2% (SD = 29.5) in EXP[JU]. Only one participant mentioned this information source in Control, whereas eleven and nine participants referred to the opponent's action tendencies in EXP and EXP[JU], respectively. Statements relating to judgement utility were reported in 34.2% (SD = 32.5) of the reports in EXP[JU], while the corresponding proportions in Control and EXP were 14.2% (SD = 23.3) and 3.3% (SD = 12.9), respectively. Statements referring to this category was reported by five participants in Control,

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[1] Independent effects for response time: EXP vs. Control, $d = 0.15 \pm 0.29$; EXP[JU] vs. Control, $d = 0.02 \pm 0.29$; EXP[JU] vs. EXP, $d = 0.14 \pm 0.31$

[2] Independent effects for response accuracy: EXP vs. Control, $d = 0.35 \pm 0.31$; EXP[JU] vs. Control, $d = 0.12 \pm 0.36$; EXP[JU] vs. EXP, $d = 0.25 \pm 0.31$
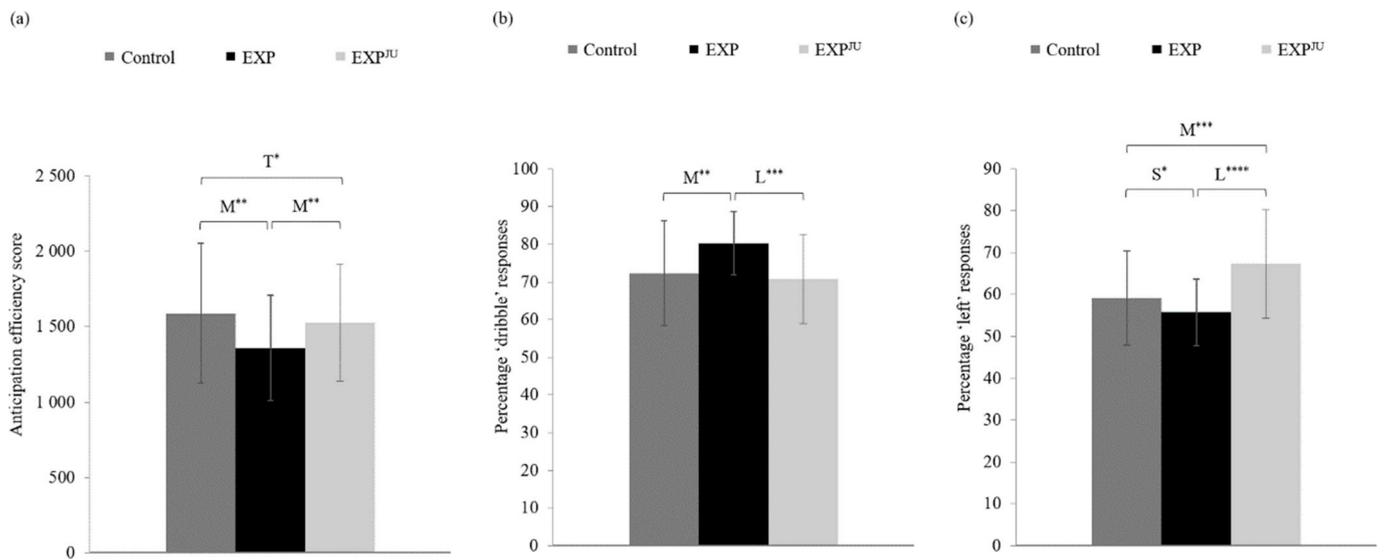
Figure 2. Anticipation Efficiency Score (a), Percentage 'Dribble' Responses (b), and Percentage 'Left' Responses (c). Means and *SD*s in each condition, as well as inferences of observed and true effects between conditions.

Note: Lower anticipation efficiency score indicates superior performance. Inference of observed effect: $0.2 > |d|$, trivial (T); $0.2 \leq |d| < 0.5$, small (S); $0.5 \leq |d| < 0.8$, moderate (M); $0.8 < |d|$, large (L). Inference of uncertainty in true effect: * possibly (25–75%); ** likely (75–95%); *** very likely (95–99.5%); **** most likely (> 99.5%).

Table 2
Unstandardised effects (M ± 90% CI) for the anticipatory judgement data across conditions.

	EXP vs. Control	EXP[JU] vs. Control	EXP[JU] vs. EXP
Anticipation efficiency score	− 231.6 ± 152.1	− 63.6 ± 149.9	166.9 ± 136.7
Percentage 'dribble' responses	7.9 ± 5.7	− 1.6 ± 6.0	− 9.6 ± 4.9
Percentage 'left' responses	− 3.4 ± 4.3	8.2 ± 5.5	11.6 ± 5.3

Note: Lower anticipation efficiency score indicates superior performance.
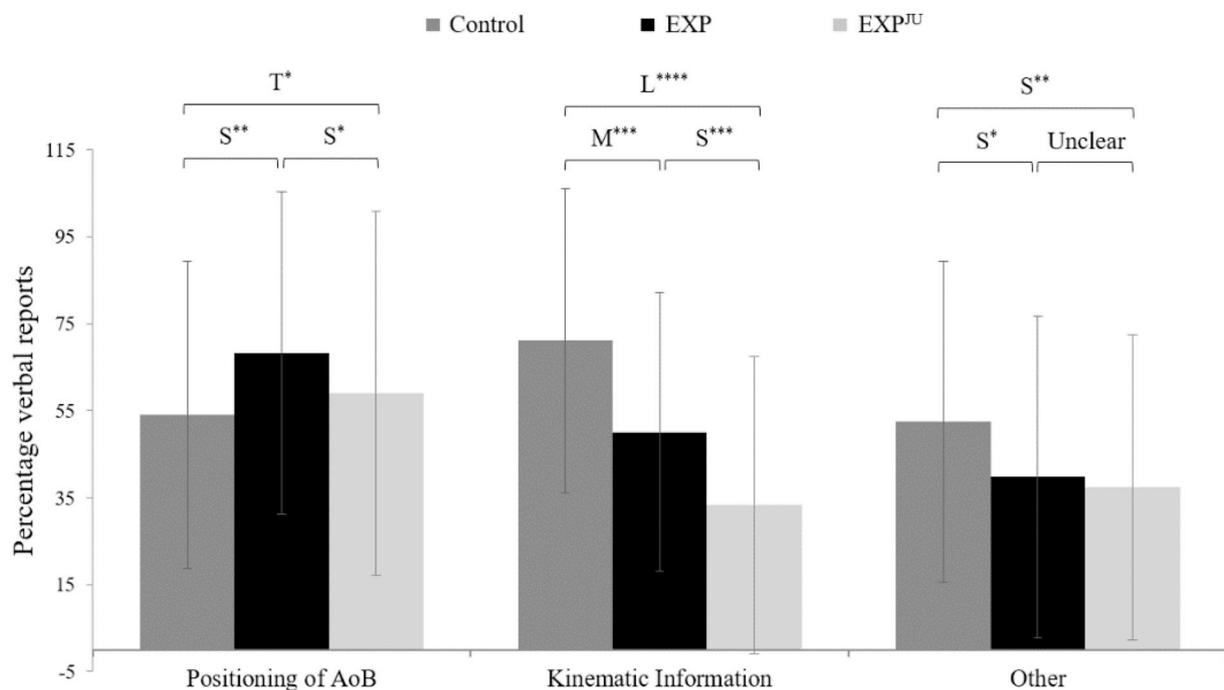
Figure 3. Percentage Verbal Reports. Means and *SD*s for the percentage of verbal reports referring to each category of visual information in each condition, as well as inferences of observed and true effects between conditions.

Note: AoB =
attacker off the ball. Inference of observed effect: $0.2 > |d|$, trivial (T); $0.2 \leq |d| < 0.5$, small (S); $0.5 \leq |d| < 0.8$, moderate (M); $0.8 < |d|$, large (L). Inference of uncertainty in true effect: * possibly (25–75%); ** likely (75–95%); *** very likely (95–99.5%); **** most likely (> 99.5%).

Table 3
Unstandardised effects (M ± 90% CI) for the percentage verbal reports of visual information across conditions.

	EXP vs. Control	EXP[JU] vs. Control	EXP[JU] vs. EXP
Positioning of AoB	14.2 ± 13.2	5.1 ± 11.5	− 9.1 ± 16.2
Kinematic information	− 21.0 ± 9.6	− 37.8 ± 15.7	− 16.8 ± 9.5
Other	− 12.7 ± 14.5	− 15.1 ± 10.3	− 2.4 ± 11.5

Note: AoB = attacker off the ball.

one participant in EXP, and twelve participants in EXP[JU].

4. Discussion

We examined the impact of judgement utility on the integration of explicit contextual priors and visual information as expert soccer players predicted the direction (left or right) of an oncoming opponent's imminent actions. The players performed the anticipation 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 (dribble = 70%; pass = 30%) were explicitly provided; and a third condition in which these contextual priors were explicitly provided, *and* judgement utility was explicitly manipulated (left judgements = high utility; right judgements = low utility). We recorded anticipatory judgements and collected retrospective think-aloud reports in all three conditions.

In line with our predictions, the explicit provision of contextual priors biased the players' anticipatory judgements toward the most likely action, given the opponent's action tendencies. This effect was manifested in the fact that the players predicted the opponent would dribble the ball to a greater extent in the condition with explicit contextual priors, compared to the condition in which no priors were provided. This finding supports previous research suggesting that expert soccer players use explicit contextual priors to inform their judgements when predicting an oncoming opponent's next move (Broadbent et al., 2018; Gredin et al., 2018). As we predicted, this biasing effect of explicit contextual priors resulted in enhanced performance, which was evidenced by superior anticipation efficiency in the condition with, compared to without, explicit priors. These findings support the growing body of research demonstrating the performance-enhancing effect of contextual priors on anticipation in sport (Broadbent et al., 2018; Gredin et al., 2018; Navia et al., 2013; Runswick et al., 2018a).

An important objective of this study was to examine the impact of judgement utility on the players' anticipation. As we hypothesised, judgement utility supressed the impact of explicit contextual priors: the proportion of 'dribble' responses did not increase when priors were accompanied by the judgement utility manipulation. In line with our predictions, this resulted in anticipation performance comparable to that in the control condition. As prescribed by Bayesian models for informational integration, this finding suggests that expert soccer players base their judgements both on the reliability of the information at hand and the costs and rewards their responses could generate (see Geisler & Diehl, 2003). In other words, it appears that judgement utility reduced the impact of contextual priors, as the players were more inclined to opt for the direction with the comparatively higher utility.

Further support for the impact of judgement utility on anticipatory judgements is apparent in the comparison made between the proportion of 'left' responses across conditions. As predicted, the proportion of responses where the players opted for a leftward outcome was higher in the condition where judgement utility was manipulated, compared to the other two conditions. Such a biasing effect of judgement utility has been demonstrated across various domains (see Canāl-Bruland et al., 2015; DeKay et al., 2009; Russo & Yong, 2011). It is noteworthy though, that the players responded 'left' more often than 'right' in all

three conditions. It may be the case that the players associated the left side with greater goal threat, due to the position on the pitch (Brooks et al., 2016) even though this information was not explicitly provided, and hence there were more 'left' responses in all three conditions. This suggestion aligns with the findings reported by Canāl-Bruland et al. (2015) demonstrating that baseball batters predicted fastballs to a greater extent than change-ups, even if they were not explicitly instructed that predicting fastballs came with greater utility. Interestingly, in the two conditions without manipulated judgement utility, the players were more inclined to respond 'left' in the condition without explicit contextual priors. In keeping with Bayesian theory (see Geisler & Diehl, 2003; Vilares & Körding, 2011), the perceived imbalance in threat between left and right outcomes may have been weighted higher in the former condition where less reliance was placed on the opponent's action tendencies.

To explore the processing priorities employed by the players during task performance, we collected immediate retrospective verbal reports of their thought processes. The data provide tentative support for our prediction that the players would refer to the opponent's action tendencies to a greater extent when this information was explicitly provided, relative to when it was not. Furthermore, when contextual priors were explicitly provided, the players reported a higher proportion of thoughts relating to the attacker off the ball, compared to the latter condition. This finding aligns with the gaze data in Gredin and colleagues' (2018) study, in which expert soccer players shifted their overt visual attention away from the opponent, and toward the attacker off the ball, when explicit contextual priors were provided. In the case of that study, and the current one, it is proposed that the players prioritised the positioning of the attacker off the ball more so when contextual priors were explicitly provided compared to when they were not. This information enabled the players to inform their anticipatory judgements in accordance with the opponent's action tendencies (i.e., when the attacker off the ball was on the left, 70% of the opponent's final actions were to the right, and vice versa).

The verbal report data in the current study also showed that the proportion of thoughts relating to the opponent's kinematic information was lower in the condition in which contextual priors were explicitly provided, relative to in the condition where they were not. This finding mirrors that of Runswick et al. (2018a), who demonstrated that an increased reliance on contextual priors came with a decreased reliance on kinematic information, when cricket batters predicted the location of forthcoming deliveries from a bowler. The previous research, and the current study, provide support for 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 Vilares & Körding, 2011).

In the condition where judgement utility was manipulated, the players engaged less in thoughts relating to the positioning of the attacker off the ball and fewer players referred to the opponent's action tendencies, compared to when explicit contextual priors were provided, but judgement utility was not manipulated. Furthermore, in the former condition, the players engaged less in thoughts relating to the opponent's kinematic information, and more players referred to the costs and/or rewards their responses could bring about, relative to in the other two conditions. In line with our predictions, these data provide tentative support that the biasing effect of judgement utility on anticipation was underpinned by changes in the thought processes that the players employed during task performance; namely, an increased concern about the costs and/or rewards their responses could bring about (see also DeKay et al., 2009; Russo & Yong, 2011).

The current study lends support to 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). However, it is important to note that the experimental design in this study did not allow us to test the predictions

prescribed by Bayesian theory in relation to the impact of contextual priors, visual information and judgement utility in a fine-grained quantitative manner. Thus, we encourage researchers to further explore the merits of Bayesian theory in this regard; for example, by adopting temporal occlusion paradigms to more tightly control the availability of visual information (e.g., Runswick, Roca, Williams, McRobert, & North, 2018b), by altering the reliability of priors in a more fine-grained manner (e.g., Gray & Cañal-Bruland, 2018), and/or by using continuous outcome possibilities, rather than a binary-choice task (e.g., Tassinari, Hudson, & Landy, 2006).

Our findings may prove highly informative to coaches and performance analysts, who typically use contextual priors to guide their players' on-pitch decision making. In situations where inaccurate and accurate judgements incur varying costs and rewards, it seems like judgement utility disrupts players' processing priorities and decreases the effectiveness of explicit contextual priors. However, it is worth noting that soccer matches are inherently complex, comprising multiple crossmodal sources of environmental information, priors that relate to multiple players and/or situations, and a multitude of potential outcomes. Thus, it is possible that the task in the current study did not evoke behaviours that we might observe under natural performance conditions (see Cañal-Bruland, Müller, Lach, & Spence, 2018; Müller & Abernethy, 2012; Vaeyens, Lenoir, Williams, Mazyn, & Philippaerts, 2007). Clearly, the impact of judgement utility should be further explored, using more naturalistic test tasks.

Another potential limitation of this study was that we did not include a condition in which we manipulated judgement utility and provided no explicit contextual priors. Adding such a condition would allow us to assess the moderating effects of judgement utility with greater certainty. However, pilot work suggested that the effects that would have been obtained in such a condition would not have been substantially different to those obtained in the EXP^{JU}.

Also, it is worth highlighting that it is possible that the players in the current study used information acquired in preceding conditions to inform their task performance in subsequent conditions. Thus, in order to mitigate potential confounding order effects, we employed a randomised and counterbalanced within-participant design, which is a well-established approach when comparing the effects of various informational conditions in sport (cf. Gray, 2009; Jackson et al., 2006; Runswick et al., 2017). To further avoid any potential familiarity effects across conditions, the trial order in each condition was randomised (cf. Gredin et al., 2018). Furthermore, it is possible that the feedback for response time and accuracy provided after each trial created another source of information that could have facilitated trial-to-trial learning. However, self-reported pilot data suggest that, without this immediate feedback about their performance, the players' motivation to engage with the task would decline over the course of testing. In the study by Gredin et al. (2018), in which the players performed a similar task and received feedback for response time and accuracy after each trial, the authors did not find any substantial performance effect when the initial 24 trials of a conditions were compared to the final 24 trials of that condition. This finding suggests that task experience, including feedback on performance after each trial, did not change the players' performance on the task. A related issue is the potential risk that the retrospective verbal reports of thoughts may have disrupted the natural thought processes in which the players engaged during task performance and, as such, influenced their behaviours on the task. In order to mitigate this risk, the players undertook 25–40 min of training on how to only report heeded thoughts in a way that they were naturally experienced during the task, rather than trying to explain, justify, or qualify their thoughts or behaviours during the task (see Eccles, 2012; Ericsson & Simon, 1980).

In summary, our findings suggest that the explicit provision of contextual priors biased expert soccer players' processing priorities during action anticipation: greater reliance was placed on the priors and context-relevant visual information, while less reliance was placed on evolving kinematic information. This, in turn, biased anticipatory judgements toward the most likely outcome, given the contextual priors, and enhanced anticipation performance. However, the biasing impact of explicit contextual priors, in regard to both anticipation and associated thought processes, was supressed when the comparative utilities associated with potential judgements differed. Under these conditions, the players became less reliant on the contextual priors and unfolding visual information, and more inclined to opt for the outcome associated with the highest rewards and the lowest costs.

Declarations of interest

None.

References

Abernethy, B., Schorer, J., Jackson, R. C., & Hagemann, N. (2012). Perceptual training methods compared: The relative efficacy of different approaches to enhancing sport-specific anticipation. *Journal of Experimental Psychology: Applied, 18*(2), 143–153. https://doi.org/10.1037/a0028452.

Batterham, A. M., & Hopkins, W. G. (2006). Making meaningful inferences about magnitudes. *International Journal of Sports Physiology and Performance, 1*(1), 50–57.

Broadbent, D. P., Gredin, N. V., Rye, J. L., Williams, A. M., & Bishop, D. T. (2018). The impact of contextual priors and anxiety on performance effectiveness and processing efficiency in anticipation. *Cognition & Emotion, 0*(0), 1–8. https://doi.org/10.1080/02699931.2018.1464434.

Brooks, J., Kerr, M., & Guttag, J. (2016). Developing a data-driven player ranking in soccer using predictive model weights. *Proceedings of the 22nd ACM SIGKDD international conference on knowledge discovery and data mining - KDD '16* (pp. 49–55). . https://doi.org/10.1145/2939672.2939695.

Cañal-Bruland, R., Filius, M. A., & Oudejans, R. R. D. (2015). Sitting on a fastball. *Journal of Motor Behavior, 47*(4), 267–270. https://doi.org/10.1080/00222895.2014.976167.

Cañal-Bruland, R., & Mann, D. L. (2015). Time to broaden the scope of research on anticipatory behavior: A case for the role of probabilistic information. *Frontiers in Psychology, 6*, 1–3. https://doi.org/10.3389/fpsyg.2015.01518.

Cañal-Bruland, R., Müller, F., Lach, B., & Spence, C. (2018). Auditory contributions to visual anticipation in tennis. *Psychology of Sport and Exercise, 36*(December 2017), 100–103. https://doi.org/10.1016/j.psychsport.2018.02.001.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Erlbaum.

Cumming, G. (2012). *Understanding the new statistics: Effect sizes, confidence intervals, and meta-analysis.* New York, NY: Routledge.

DeKay, M. L., Patiño-Echeverri, D., & Fischbeck, P. S. (2009). Distortion of probability and outcome information in risky decisions. *Organizational Behavior and Human Decision Processes, 109*(1), 79–92. https://doi.org/10.1016/j.obhdp.2008.12.001.

Eccles, D. W. (2012). Verbal reports of cognitive processes. In J. Tenenbaum, R. C. Eklund, & A. Kamata (Eds.). *Measurement in sport and exercise psychology*. Champaign, IL: Human Kinetics.

Ericsson, K. A., & Simon, H. A. (1980). Verbal reports as data. *Psychological Review, 87*(3), 215–251. https://doi.org/10.1037/0033-295X.87.3.215.

Farrow, D., Abernethy, B., & Jackson, R. C. (2005). Probing expert anticipation with the temporal occlusion paradigm: Experimental investigations of some methodological issues. *Motor Control, 9*(3), 330–349. https://doi.org/10.1123/mcj.9.3.330.

Geisler, W. S., & Diehl, R. L. (2003). A Bayesian approach to the evolution of perceptual and cognitive systems. *Cognitive Science, 27*(3), 379–402. https://doi.org/10.1016/S0364-0213(03)00009-0.

Gray, R. (2009). How do batters use visual, auditory, and tactile information about the success of a baseball swing? *Research Quarterly for Exercise & Sport, 80*(3), 491–501. https://doi.org/10.1080/02701367.2009.10599587.

Gray, R., & Cañal-Bruland, R. (2018). Integrating visual trajectory and probabilistic information in baseball batting. *Psychology of Sport and Exercise, 36*(January), 123–131. https://doi.org/10.1016/j.psychsport.2018.02.009.

Gredin, N. V., Bishop, D. T., Broadbent, D. P., Tucker, A., & Williams, A. M. (2018). Experts integrate contextual priors and environmental information to improve anticipation efficiency. *Journal of Experimental Psychology: Applied.*

Hopkins, W. G. (2002). Probabilities of clinical or practical significance. *Sportscience, 6*. Retrieved from http://www.sportsci.org/jour/0201/wghprob.htm.

Hopkins, W. G. (2006). Estimating sample size for magnitude-based inferences. *Sportscience, 10*, 63–70.

Hopkins, W. G., Marchall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine & Science in Sports & Exercise, 41*(1), 3–13. https://doi.org/10.1249/MSS.0b013e31818cb278.

Jackson, R. C., Ashford, K. J., & Norsworthy, G. (2006). Attentional focus, dispositional reinvestment, and skilled motor performance under pressure. *Journal of Sport & Exercise Psychology, 28*, 49–68.

Knill, D. C., & Pouget, A. (2004). The Bayesian brain: The role of uncertainty in neural coding and computation. *Trends in Neurosciences, 27*(12), 712–719. https://doi.org/10.1016/j.tins.2004.10.007.

Loffing, F., & Cañal-Bruland, R. (2017). Anticipation in sport. *Current Opinion in Psychology, 16*, 6–11. https://doi.org/10.1016/j.copsyc.2017.03.008.

Loffing, F., & Hagemann, N. (2014). Skill differences in visual anticipation of type of throw in team-handball penalties. *Psychology of Sport and Exercise, 15*(3), 260–267. https://doi.org/10.1016/j.psychsport.2014.01.006.

Memmert, D., Lemmink, K. A. P. M., & Sampaio, J. (2017). Current approaches to tactical performance analyses in soccer using position data. *Sports Medicine, 47*(1), 1–10. https://doi.org/10.1007/s40279-016-0562-5.

Müller, S., & Abernethy, B. (2012). Expert anticipatory skill in striking sports: A review and a model. *Research Quarterly for Exercise & Sport, 83*(2), 175–187. https://doi.org/10.1080/02701367.2012.10599848.

Murphy, C. P., Jackson, R. C., Cooke, K., Roca, A., Benguigui, N., & Williams, A. M. (2016). Contextual information and perceptual-cognitive expertise in a dynamic, temporally-constrained task. *Journal of Experimental Psychology: Applied, 22*(4), 455–470. https://doi.org/10.1037/xap0000094.

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

Perneger, T. V. (1998). What's wrong with Bonferroni adjustments. *BMJ, 316*(7139), 1236–1238. https://doi.org/10.1136/bmj.316.7139.1236.

Roca, A., Ford, P. R., McRobert, A. P., & Williams, A. M. (2013). Perceptual-cognitive skills and their interaction as a function of task constraints in soccer. *Journal of Sport & Exercise Psychology, 35*(2), 144–155. https://doi.org/10.1123/jsep.35.2.144.

Rothman, K. J. (1990). No adjustments are needed for multiple comparisons. *Epidemiology, 1*, 43–46. https://doi.org/10.1016/S0360-3199(98)00119-0.

Runswick, O. R., Roca, A., Williams, A. M., Bezodis, N. E., McRobert, A. P., & North, J. S. (2018a). The impact of contextual information and a secondary task on anticipation performance: An interpretation using cognitive load theory. *Applied Cognitive Psychology, 32*, 141–149. https://doi.org/10.1002/acp.3386.

Runswick, Oliver R., Roca, A., Williams, A. M., Bezodis, N. E., & North, J. S. (2017). The effects of anxiety and situation-specific context on perceptual–motor skill: A multi-level investigation. *Psychological Research, 0*(0), 0. https://doi.org/10.1007/s00426-017-0856-8.

Runswick, Oliver R., Roca, A., Williams, A. M., McRobert, A. P., & North, J. S. (2018b). The temporal integration of information during anticipation. *Psychology of Sport and Exercise, 37*(May), 100–108. https://doi.org/10.1016/j.psychsport.2018.05.001.

Russo, J. E., & Yong, K. (2011). The distortion of information to support an emerging evaluation of risk. *Journal of Econometrics, 162*(1), 132–139. https://doi.org/10.1016/j.jeconom.2010.07.004.

Tassinari, H., Hudson, T. E., & Landy, M. S. (2006). Combining priors and noisy visual cues in a rapid pointing task. *Journal of Neuroscience, 26*(40), 10154–10163. https://doi.org/10.1523/JNEUROSCI.2779-06.2006.

Vaeyens, R., Lenoir, M., Williams, A. M., Mazyn, L., & Philippaerts, R. M. (2007). The effects of task constraints on visual search behavior and decision-making skill in youth soccer players. *Journal of Sport & Exercise Psychology, 29*(2), 147–169. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/17568064.

Vilares, I., & Körding, K. P. (2011). Bayesian models: The structure of the world, uncertainty, behavior, and the brain. *Annals of the New York Academy of Sciences, 1224*(1), 22–39. https://doi.org/10.1111/j.1749-6632.2011.05965.x.

Wallsten, T. (1981). Physician and medical student bias in evaluating diagnostic information. *Medical Decision Making, 1*(2), 145–164.

Williams, A. M. (2000). Perceptual skill in soccer: Implications for talent identification and development. *Journal of Sports Sciences, 18*(9), 737–750. https://doi.org/10.1080/02640410050120113.

Williams, A. M., & Jackson, R. C. (2018). Psychology of Sport & Exercise Anticipation in sport : Fifty years on , what have we learned and what research still needs to be undertaken ? *Psychology of Sport and Exercise,* (August), 1–9. https://doi.org/10.1016/j.psychsport.2018.11.014.

Wright, M. J., Bishop, D. T., Jackson, R. C., & Abernethy, B. (2013). Brain regions concerned with the identification of deceptive soccer moves by higher-skilled and lower-skilled players. *Frontiers in Human Neuroscience, 7*(December), 1–15. https://doi.org/10.3389/fnhum.2013.00851.