Journal of Sports Sciences

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rjsp20

Integrating explicit contextual priors and kinematic information during anticipation

N. Viktor Gredin, Daniel T. Bishop, A. Mark Williams & David P. Broadbent

To cite this article: N. Viktor Gredin, Daniel T. Bishop, A. Mark Williams & David P. Broadbent (2021) Integrating explicit contextual priors and kinematic information during anticipation, Journal of Sports Sciences, 39:7, 783-791, DOI: 10.1080/02640414.2020.1845494

To link to this article: https://doi.org/10.1080/02640414.2020.1845494

JOURNAL OF SPORTS SCIENCES
2021, VOL. 39, NO. 7, 783–791
https://doi.org/10.1080/02640414.2020.1845494

Routledge
Taylor & Francis Group

SPORTS PERFORMANCE

OPEN ACCESS Check for updates

Integrating explicit contextual priors and kinematic information during anticipation

N. Viktor Gredin[a], Daniel T. Bishop[a,b], A. Mark Williams[c] and David P. Broadbent[a,b]

[a]Division of Sport, Health and Exercise Sciences, Department of Life Sciences, Brunel University London, London, UK; [b]Centre for Cognitive Neuroscience, College of Health and Life Sciences, Brunel University London, London, UK; [c]Department of Health, Kinesiology, and Recreation, University of Utah, Salt Lake City, UT, USA

ABSTRACT
We examined the interaction between explicit contextual priors and kinematic information during anticipation in soccer. We employed a video-based anticipation task where skilled soccer players had to predict the direction of the imminent actions of an attacking opponent in possession of the ball. The players performed the task both with and without explicit contextual priors pertaining to the opponent's action tendencies. The strength of the opponent's action tendencies was altered in order to manipulate the reliability of contextual priors (*low* vs. *high*). Moreover, the reliability of kinematic information (*low* vs. *high*) was manipulated using the temporal occlusion paradigm. The explicit provision of contextual priors biased anticipation towards the most likely direction, given the opponent's action tendencies, and resulted in enhanced performance. This effect was greater under conditions where the reliability of kinematic information was low rather than high. When the reliability of kinematic information was high, the players used explicit contextual priors of high, but not low, reliability to inform their judgements. Findings suggest that athletes employ reliability-based strategies when integrating contextual priors with kinematic information during anticipation. The impact of explicit contextual priors is dependent on the reliability both of the priors and the evolving kinematic information.

ARTICLE HISTORY
Accepted 30 October 2020

KEYWORDS
Bayesian; uncertainty; decision making; probabilistic information; soccer

Introduction

The ability to anticipate others' actions is important when performing in dynamic and rapidly evolving environments, such as those encountered in many sports (Williams & Jackson, 2019). In soccer, for example, fast and accurate anticipation of an oncoming attacker's next move can be crucial in order for a defender to select and execute an appropriate action in time to prevent a goal-scoring opportunity (Williams, 2000). It is well-reported that experts are better than less-expert athletes in using biological motion, or kinematic information, which allows them to anticipate opponents' actions faster and more accurately (Mann et al., 2007). However, in recent years, several researchers have explored the effect of providing contextual (non-kinematic) sources of information (Cañal-Bruland & Mann, 2015), referred to in this paper as contextual priors. Contextual priors may be viewed as *stable*, remaining unchanged throughout an action, such as an opponent's action tendencies, or *dynamic*, unfolding during the action, such as an opponent's position on the field of play (Williams & Jackson, 2019). In the quest to develop an overarching framework that might explain anticipation performance, it has been suggested that athletes may employ Bayesian reliability-based strategies in order to integrate contextual priors with evolving visual information (Loffing & Cañal-Bruland, 2017). The dependency on contextual priors and visual information is modulated by the reliability of the information at hand, with greater weight assigned to information of higher reliability (Vilares & Körding, 2011). However, the applicability of this assumption when explaining anticipation in sport needs to be further explored. In the current study, we examine the interaction between explicit contextual priors and kinematic information of various levels of reliability during anticipation in skilled soccer players.

When required to anticipate the actions of opponents, athletes alter their processing priorities over time according to the reliability of the visual information at hand. As unfolding visual information becomes more specific, and therefore more reliable, with regard to the forthcoming action, athletes refine their anticipatory judgements accordingly (Müller & Abernethy, 2012). Several researchers have employed the temporal occlusion paradigm to demonstrate that access to later, more reliable, kinematic information enhances performance when athletes try to predict an oncoming opponent's next move (e.g., Farrow et al., 2005; Loffing & Hagemann, 2014; Wright et al., 2013). Farrow et al. (2005) demonstrated that expert tennis players were more accurate in predicting the direction of forthcoming serves when the video stimuli 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). Additionally, the authors compared videos with various occlusion points around ball-racket contact to those with moving windows that captured different phases of the service action. The reliability of visual information – expressed by its impact on response accuracy – was not modulated by the total amount of kinematic information available, but rather by the *relevance* of the opponent's kinematics with regard to serve direction.

As well as kinematic information, a priori probabilistic information, in the form of expectations and beliefs, is likely to influence anticipatory processes – yet our understanding of

CONTACT David P. Broadbent david.broadbent@brunel.ac.uk

how such contextual priors are used by athletes is limited (Cañal-Bruland & Mann, 2015). Bayesian models of probabilistic inference may provide a suitable framework to elucidate the strategies by which athletes integrate contextual priors and evolving visual information during anticipation (Loffing & Cañal-Bruland, 2017). According to Bayesian theories, people strive to reduce 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 information presented, and vice versa (Vilares & Körding, 2011). Several researchers have reported, 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), that the extent to which people rely on prior and current information depends upon the comparative reliability associated with the information at hand. Furthermore, in the domain of forensic science, Dror et al. (2005) reported 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. 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).

More recently, researchers have explored the impact of the reliability of information when examining an athlete's reliance on contextual priors and visual information during anticipation. Gredin et al. (2018) used a 2-versus-2 video-based anticipation task in soccer where expert players had to predict the direction of an oncoming opponent's imminent actions, both with and without explicitly provided contextual priors regarding the opponent's action tendencies. To utilise this stable contextual prior, players had to use the positioning of the opponent off the ball (i.e., a dynamic contextual prior). The explicit provision of information about opponent action tendencies altered players' allocation of overt visual attention, towards the opponent off the ball, and biased their anticipatory judgements towards the most likely action, given the opponent's action tendencies, which resulted in enhanced performance on the task (see also Gredin et al., 2020, 2019). Gredin et al. (2018) demonstrated that the impact of explicit contextual priors was greater early in the trial, while the players relied more upon evolving kinematic information later in the trial (i.e., closer to the key point of action). In keeping with Bayesian theories, the authors proposed that expert players relied less on the opponent action tendencies as the opponent's kinematic information became more reliable during later stages of the trial. However, the authors did not standardise the response times across trials or participants and, as such, did not control for the reliability of the visual information available prior to each response. A more controlled approach is required to effectively test the assumption that the reliability of visual information modulates the impact of contextual priors during anticipation.

Helm et al. (2020) systematically manipulated the reliability of opponent kinematics when handball players anticipated the direction of penalty throws. Opponents were simulated by human-like avatars with various levels of kinematic ambiguity: (1) exaggerated genuine throws; (2) genuine throws; (3) morphs with 25% disguised kinematics; (4) morphs with 50% disguised kinematics; (5) morphs with 75% disguised kinematics; (6) disguised throws; (7) exaggerated disguised throws. Furthermore, the authors manipulated the reliability of the contextual priors, relating to the action preferences of the penalty taker, that were explicitly provided to participants prior to task performance: 25% probability of disguised throws; 50% probability of disguised throws; and 75% probability of disguised throws. The actual probability of a disguised throw was 50%, so this condition was used as the control. Participants were more likely to classify ambiguous movements as genuine when they were explicitly informed that the opponent was less likely to produce disguised throws, and vice versa (see also Jackson et al., 2020). Moreover, the greater the degree of ambiguity in the kinematic information, the more weight placed on the contextual priors. The authors concluded that athletes seek to optimize anticipation by integrating kinematic information and contextual priors in a Bayesian reliability-based manner.

Runswick, Roca, Williams et al. (2018a) employed a temporal occlusion paradigm during a simulated cricket batting task, in which batters had to predict the location of forthcoming deliveries from bowlers. The video stimuli were occluded at various time points relative to ball release, which required the batters to respond under conditions where the bowler's kinematics and the ball afforded varying levels of reliability about 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 relied on by expert batters. 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 from the bowler's kinematics and ball flight to anticipate.

In a similar vein, Gray and Cañal-Bruland (2018) used a temporal occlusion paradigm to manipulate the reliability of visual information when examining the impact of explicitly provided contextual priors pertaining to a pitcher's action tendencies during a virtual batting task in baseball. The performance-enhancing effect of explicit contextual priors decreased as the availability of ball flight information increased (i.e., as the ball flight became a more reliable cue). However, these authors altered not only the reliability of evolving visual information, but also that of contextual priors by altering the strength of the pitcher's action tendencies (e.g., the chance that the pitcher would throw a fastball was either 50%, 65%, or 80%). The beneficial effects of explicit contextual priors on performance increased with the reliability of the priors (i.e., as the strength of the pitcher's action tendencies increased). The integration of contextual priors is moderated by the reliability of current visual information *and* the reliability of the priors themselves. However, it remains unclear whether the performance-enhancing effects of contextual priors pertaining to strong, rather than subtle, action tendencies reported by Gray and Cañal-Bruland (2018) were driven by the strength of the pitcher's action tendencies, or merely by the number of trials wherein the pitcher performed the most likely pitch, given his action tendencies. It is possible that the extent to which the batters anticipated the "most likely pitch" did not differ across conditions that revealed subtle and strong action tendencies, but the benefits of doing so were greater in the latter condition. Furthermore, unlike the study by Gredin et al. (2018), participants in the study by Gray and Cañal-Bruland (2018) and the one by Runswick et al. (2018a) did not have to take into account dynamic contextual priors that emerged over the course of a trial in order to make use of the opponent action tendencies. In highly dynamic performance contexts, the dependency between stable and dynamic contextual priors and progressively evolving visual information may be a vital component that researchers should consider when examining athletes' anticipatory processes under such conditions (e.g., in soccer).

In the current study, we adopted the same anticipation task as employed by Gredin et al. (2018), in which expert soccer players were required to predict the direction of an oncoming opponent's actions, either with or without explicit contextual priors regarding the opponent's action tendencies. However, to standardise the reliability of visual information prior to each response, a temporal occlusion paradigm was employed. The players performed the task in the presence of kinematic information of low (early occlusion point, more distant from the key point of action) and high (late occlusion point, closer to the key point of action) 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. We hypothesised that the explicit provision of contextual priors would bias anticipation towards the most likely action, given the opponent's action tendencies, and enhance performance (see Broadbent et al., 2018; Gredin et al., 2018, 2019). In line with Bayesian models for probabilistic inference, we predicted that this effect would be modulated by the reliability of the information at hand (see Vilares & Körding, 2011). We assumed that this finding 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 the proportion of responses where the players predicted that the opponent would dribble the ball and that this biasing effect would result in enhanced task performance. In keeping with Bayesian theory, we hypothesised that these effects would be more pronounced when the priors were associated with high, rather than low, reliability. Finally, we predicted that the effects of explicit contextual priors would decrease as the reliability of the opponent's kinematic information increased (cf. Gray & Cañal-Bruland, 2018; Runswick et al., 2018a). Only highly reliable explicit contextual priors would bias judgements and enhance performance under conditions where highly reliable kinematic information was available.

Methods

Participants

Altogether, 15 (M_{age} = 25 years, *SD* = 4) semi-professional and local club-level female soccer players participated. A spreadsheet (Hopkins, 2020) was used to estimate the number of participants needed to ensure adequate precision of our outcome 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 previous reports of the biasing effect of explicit contextual priors on anticipation (i.e., changes in % "dribble" responses: observed effect = 7.9, within-subject SD = 13.9, between-subject SD = 13.9, and smallest worthwhile effect = 2.4; Gredin et al., 2019). On average, the players had 14 years (*SD* = 3) of competitive experience in soccer and took part in 5 hours (*SD* = 2) of practice or match play per week. Participants were classified as "skilled" as they had accumulated more than 10 years of coach-led team practice, which typically comprises activities specifically designed to improve sport specific performance (see Ericsson & Ward, 2007; Ward et al., 2007). The study was approved by the Research Ethics Committee of the lead institution and conformed to the recommendations of the Declaration of Helsinki. Participants provided informed consent in writing.

Test stimuli and task

The test stimuli represented 2-versus-2 counterattacking scenarios in soccer and were filmed on artificial turf 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 video camera was attached to a moving trolley, at a height of 1.7 m, to replicate the perspective of a central defender facing oncoming opponents while simultaneously moving backwards. These scenarios were chosen to present a high level of threat and to put the participant under severe time constraints. In such situations, athletes make anticipatory judgements more frequently (Triolet et al., 2013) and rely on their prior expectations to a greater extent (Roca et al., 2013), than in less pressured situations. The test film was edited using Pinnacle Studio software (v15; Pinnacle, Ottawa, Canada). Two qualified soccer coaches (UEFA A Licence holders) independently verified that the final test footage of 120 video sequences were representative of actual game play, that is, they reflected changes in visual information that would occur under natural performance conditions, in which a player defending against a 2-versus-2 counterattack, in a realistic manner. Only sequences that were verified by both coaches were included in the final test footage.

Each sequence showed three soccer players (all males) who were a similar skill level to the participants; one attacking player in possession of the ball (this player is termed "the opponent"), a second attacker off the ball, and one defender who was marking the second attacker throughout the sequence (see Figure 1). The videos were projected onto a 4.1 × 2.3 m projection screen and the participant viewed the scenarios from a first-person perspective, as if they were the second defender. 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 (after ~5 s), the opponent could either pass the ball to his teammate (positioned either to the left or the right of the opponent) or dribble the ball in the opposite direction to his teammate.

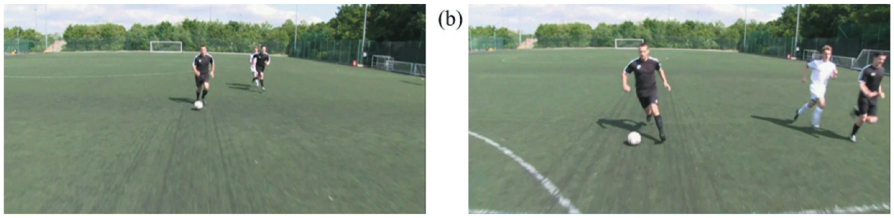
(a)  (b)

Figure 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).

Halfway through each trial (after ~2.5 s), the sequence was occluded, and a black screen was displayed. Upon occlusion, participants had to predict the direction (left or right) of the opponent's final action. The occlusion point was chosen as it enabled the participant to determine the run trajectory of the attacker off the ball (i.e., a dynamic contextual prior), information which they had to integrate with their prior knowledge of the opponent's action tendencies (i.e., a stable contextual prior) when predicting the final action (see Gredin et al., 2018). Furthermore, prior to this occlusion point, the kinematic information provided by the opponent on the ball was considered to be associated with high uncertainty with regard to the direction of the final action. Therefore, these responses reflected the participant's anticipation under *low-reliability* kinematic information (see Figure 1(a)). We recorded responses 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 of 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 the 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 anticipation under *high-reliability* kinematic information (see Figure 1(b)). Using the same counterattacking scenarios as we did in the current study, Gredin et al. (2018) reported that the time between emergence of pertinent kinematic information and the last foot-ball contact of the opponent's final action was shorter when the opponent passed the ball, than when he dribbled the ball. Thus, in order to prevent dribbling actions from providing more predictive information than passing actions, we chose different occlusion points for dribble (240 ms prior to last foot-ball contact) and pass (120 ms prior to last foot-ball contact) scenarios. Pilot tests with skilled soccer players, none of whom participated in the current study, demonstrated that these occlusion points ensured that participants could predict both action types at a level that was above chance but below a ceiling level of performance. After their response at the second occlusion point, feedback regarding their final response accuracy was displayed on screen. Performance feedback was provided to motivate participants to stay engaged with the task throughout testing (cf. Gredin et al., 2019). At each occlusion point, the black screen was shown for a maximum of 5 s, and the participants were instructed to respond quickly and accurately. If participants responded after the occlusion screen, then that response was deemed incorrect. Participants were positioned 4 m in front of the screen at the start of each trial, but was free to move as wished during task performance, in order to maximise the real-world representativeness of the task. Since in a real match, players are normally aware of the position of the ball and other players, each half of the trial started with a frozen frame for 1 s to allow the participant to detect this information (cf. Gredin et al., 2018).

Procedure

Prior to testing, participants were given an overview of the experimental protocol and presented with six familiarisation trials to become accustomed to the experimental setup and the response requirements. After the familiarisation trials, participants performed three blocks of ten test trials under two conditions differing in terms of 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%. The responses under this condition reflected the participant's anticipation 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. The responses in this condition reflected the participant's anticipation 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 applied to the conditions where contextual priors were not explicitly provided). The strength of the opponent's action tendencies for low- and high-reliability contextual priors was calculated from previous research demonstrating performance effects of explicit contextual priors pertaining to action tendencies of ~70% and ~30% for dribble and pass, respectively (Gredin et al., 2018, 2020, 2019). Specifically, we either decreased the chances of a dribble and increased the chances of a pass (low-reliability contextual priors) or increased the chances of a dribble and decreased the chances of a pass (high-reliability contextual priors) by ~10% points.

In summary, participants were required to predict the direction of the oncoming opponent's final action under four conditions which varied in informational uncertainty (see Figure 2).

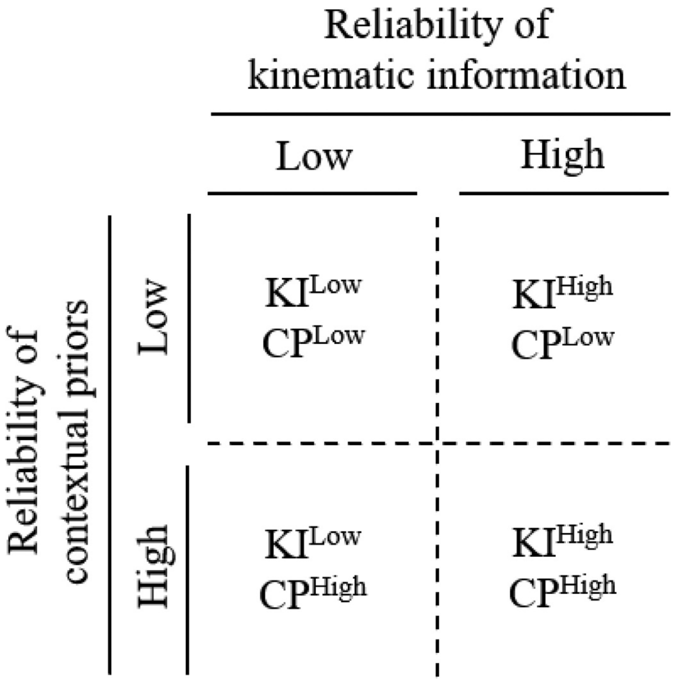


Figure 2. Experimental Conditions. The participant predicted the direction of the opponent's final action under four conditions that varied in the reliability of kinematic information and contextual priors. Note: the task was completed under these conditions, both with and without explicit provision of contextual priors.

These four conditions arose when: both kinematic information and contextual priors were low in reliability ($KI^{Low}CP^{Low}$); kinematic information and contextual priors were high and low in their reliability, respectively ($KI^{High}CP^{Low}$); kinematic information and contextual priors were low and high in their reliability, respectively ($KI^{Low}CP^{High}$); and both kinematic information and contextual priors were high in reliability ($KI^{High}CP^{High}$). All participants performed the task under these conditions, both with and without explicit provision of contextual priors. The presentation order of conditions containing low- and high-reliability contextual priors, and whether they explicitly provided or not, was randomised and counterbalanced across participants using a Latin square design. This randomised and counterbalanced within-participant design was used in order to control for inter-individual variability and to minimise the influence of potential learning and carryover effects (cf. Gray, 2009; Jackson et al., 2006; Runswick, Roca, Williams et al., 2018b). To eliminate the influence of trial-specific characteristics, the trials presented with and without explicit contextual priors were the same in each condition. However, to avoid any potential familiarity effects, the order in which the trials were presented with and without explicit contextual priors was randomised (cf. Gredin et al., 2018). In total, the participant performed 120 test trials and the entire session was completed within 90 minutes.

Data analysis

The impact of the explicit provision of contextual priors on anticipation performance, expressed as response accuracy, was evaluated within each condition. To assess the biasing effects of explicit contextual priors on anticipation, the percentage of responses where participants opted for "dribble", with and without explicit priors, was compared 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; cf. Gredin et al., 2019).

The descriptive statistics are reported as means and *SD*s. We report magnitudes of observed effects along with their 90% confidence intervals (CIs) as standardised (*d*) and unstandardised units. We chose the 90% confidence level because the chances that the true value of the effect would be below the lower limit or above the upper limit are both 5%, which is interpreted as very unlikely (Hopkins, 2002). The effects were standardised by dividing the mean effect by the combined *SD* (Cumming, 2012). In the absence of data to enable prior statistical quantification of thresholds for meaningful effects, we reported the observed effects according to the following scale: $0.2 > |d|$, trivial; $0.2 \le |d| < 0.5$, small; $0.5 \le |d| < 0.8$, moderate; $0.8 \le |d|$, large (Cohen, 1988). We used Cohen's standardised unit for the smallest substantial effect (0.2) as the threshold value for estimating the uncertainties in the true effect to be meaningful (Cumming, 2012; Winter et al., 2014). These 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, meaning that there is ≥5% that the true effect could be substantially negative and ≥5% that it could be substantially positive, then then the effect was deemed unclear. We reported clear effects as the magnitude of the observed value, which were evaluated probabilistically as described above (Batterham & Hopkins, 2006; Wilkinson, 2014). We decided against using traditional null-hypothesis significance testing (Neyman & Pearson, 1933) in favour of interpreting the point estimates and their 90% confidence intervals against threshold values for meaningful effects. The latter approach was chosen as it is more informative to report the magnitude of observed effects and the precision of estimates, than whether observed effects are statistically significant according to a specified alpha level (e.g., $p < .05$; (Cumming, 2014; Wasserstein et al., 2019; Wilkinson, 2014).

Results

The response accuracy scores in each condition, both in the absence and presence of explicitly provided contextual priors, are presented in Figure 3(a). The explicit provision of contextual priors resulted in a small possible increase in response accuracy in $KI^{Low}CP^{Low}$ ($d = 0.39 \pm 0.61$) and a moderate likely increase in $KI^{Low}CP^{High}$ $d = (0.59 \pm 0.42)$. No clear effect was obtained when the change in accuracy in $KI^{Low}CP^{Low}$ was compared to that in $KI^{Low}CP^{High}$. A large likely effect was obtained when the effect of explicit contextual priors in $KI^{High}CP^{High}$ was compared to that in $KI^{High}CP^{Low}$ ($d = 0.89 \pm 0.74$); a moderate likely increase in response accuracy was found in the former condition ($d = 0.70 \pm 0.52$), whereas no clear effect was found in the latter.

Figure 3(b) shows the percentage of responses where the participants predicted that the opponent would dribble the ball, in each condition, both in the absence and presence of explicit contextual priors. A moderate very likely and a moderate likely

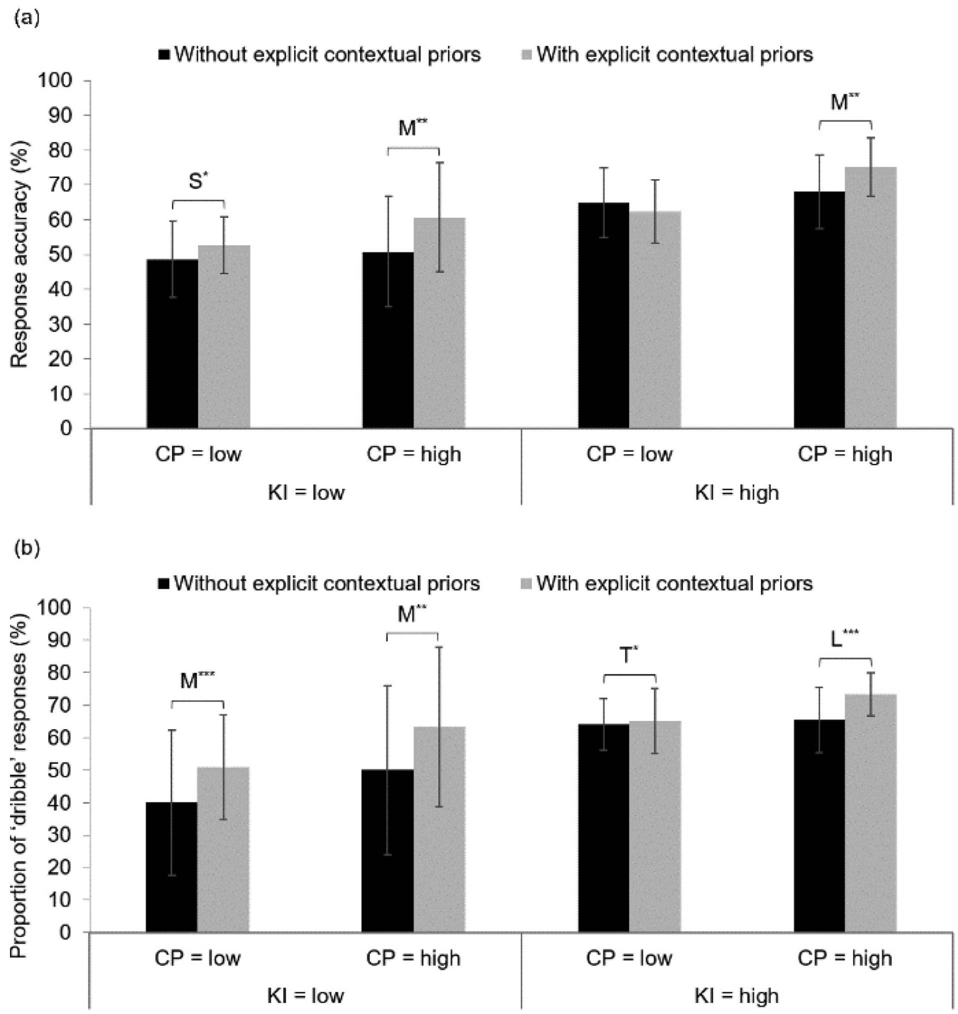


Figure 3. Response Accuracy (a) and Proportion of "Dribble" Responses (b). Means and *SD*s, as well as inferences of observed and true effects of explicit contextual priors in each condition. Inference of observed effects: 0.2 > |*d*|, trivial (T); 0.2 ≤ |*d*| < 0.5, small (S); 0.5 ≤ |*d*| < 0.8, moderate (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.

effect were found in $KI^{Low}CP^{Low}$ ($d = 0.53 \pm 0.33$) and $KI^{Low}CP^{High}$ ($d = 0.50 \pm 0.37$), respectively; the participants responded "dribble" to a greater extent when contextual priors were explicitly provided, relative to when they were not. No clear effect was obtained when the effect obtained in $KI^{Low}CP^{Low}$ was compared to that in $KI^{Low}CP^{High}$. A moderate very likely effect was obtained when the effect of explicit contextual priors in $KI^{High}CP^{High}$ was compared to that in $KI^{High}CP^{Low}$ ($d = 0.74 \pm 0.40$); a large very likely increase in percentage "dribble" responses was found in $KI^{High}CP^{High}$ ($d = 0.89 \pm 0.51$), whereas only a trivial possible effect was found in $KI^{High}CP^{Low}$ ($d = 0.12 \pm 0.30$).

The unstandardised effects that explicit contextual priors had on response accuracy and percentage of "dribble" responses in each condition are shown in Table 1.

Table 1. Unstandardised Effects (M ± 90% CI) of Explicit Contextual Priors on Response Accuracy (%) and Proportion of "Dribble" Responses (%) in the Four Conditions.

	KI = low		KI = high	
	CP = low	CP = high	CP = low	CP = high
Response accuracy	4.0 ± 6.1	9.8 ± 7.0	−2.4 ± 6.3	7.1 ± 5.3
Proportion of "dribble" responses	10.9 ± 6.7	13.3 ± 9.8	1.1 ± 2.8	8.0 ± 4.6

Note: Effects in each condition were calculated by subtracting the group mean for accurate responses or percentage "dribble" responses when no contextual priors were explicitly provided, from the group mean for the corresponding dependent variable when contextual priors were explicitly provided. 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.

Discussion

We examined the interaction between explicit contextual priors and kinematic information of various levels of reliability during anticipation in soccer. Specifically, skilled soccer players predicted the direction of an opponent's forthcoming actions, both with and without explicit provision of 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 our predictions, when the reliability of kinematic information was low (i.e., in the first half of the trial), explicit contextual priors of both low (dribble = 60%; pass = 40%) and high (dribble = 80%; pass = 20%) reliability increased the proportion of "dribble" responses and resulted in enhanced anticipation performance. In the absence of reliable kinematic information, the explicit provision of contextual priors biased the players' anticipation towards the most likely outcome, given the action tendencies. This interpretation aligns with that of Gredin et al. (2018) in regard to the biasing effects of explicit contextual priors on anticipatory processes. Namely, before reliable kinematic information of the attacker in possession emerged, expert players used the dynamic contextual prior related to the position of the attacker off the ball, which occurred early during the first half of each trial, to inform their use of the opponent's action tendencies effectively (i.e., when the attacker off the ball ran to the left, 60% [low-reliability contextual priors] or 80% [high-reliability contextual priors] of the opponent's final actions were to the right, and vice versa). In contrast to our predictions, when the reliability of the kinematic information was low, there were no clear differences between the effect of low- and high-reliability contextual priors – neither for the proportion of "dribble" responses nor response accuracy. 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 of the information pertaining to the opponent's action tendencies, regardless of whether those tendencies were subtle or strong, may have been considered as high, relative to the reliability of kinematic information in the first half of any given trial.

As predicted, in the presence of highly reliable kinematic information, explicit contextual priors of high, but not low, reliability increased the proportion of "dribble" responses and enhanced anticipation performance. The fact that the effects of low-reliability priors, which were revealed when the reliability of kinematic information was low, were not found when highly reliable kinematic information was available, suggests that the impact of explicit contextual priors decreased as the reliability of the opponent's kinematic information increased. Such 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; Helm et al., 2020; Runswick et al., 2018a). Findings align with the Bayesian notion that the impact of contextual priors is moderated by the reliability of current visual information (Vilares & Körding, 2011).

The idea that skilled soccer players may employ Bayesian reliability-based strategies to integrate explicit contextual priors and visual information during anticipation was recently proposed in a study by Gredin et al. (2018). However, in that study, the authors did not standardise the amount of visual information available across trials and participants, and as such did not control for the reliability of visual information available prior to each response. The results from the temporal occlusion paradigm adopted in the current study provide support for the contention that the players employed reliability-based strategies to integrate explicit contextual priors relating to an opponent's action tendencies and kinematic information during task performance. The interaction of explicit contextual priors and kinematic information was evident when comparing the impact of low- and high-reliability priors after the second half of the trials; that is, in the presence of kinematic information of high reliability. The greater performance-enhancing effect that was found when explicit priors of high, rather than low, reliability were provided aligns with the results reported by Gray and Cañal-Bruland (2018). Gray and Cañal-Bruland (2018) suggested that the beneficial effect of explicit priors pertaining to an opponent's action tendencies increases as the strength of the opponent's action tendencies increases. However, the current study builds upon this work by demonstrating that the greater benefit generated by priors of high, rather than low, reliability was driven by an increased reliance on the opponent's action tendencies, which was manifested in a greater increase in the proportion of "dribble" responses. Furthermore, the fact that a difference between low- and high-reliability priors was not found in the presence of low-reliability kinematic information in the current study provides further support for the notion that the use of explicit contextual priors is dependent on the reliability of the priors themselves, as well as the reliability of evolving kinematic information. In other words, the relative uncertainty levels associated with contextual priors of low and high reliability are more relevant in the presence of highly reliable kinematic information.

Several actions were taken to increase the real-world representativeness of the video-based anticipation task. First, the video stimuli were filmed from the viewing perspective of a defender facing oncoming players while moving backwards, as occurs in matches. Second, the stimuli were projected onto a life-size projection screen rather than onto a small screen to increase realism (Williams & Davids, 1998). Third, in order to increase movement fidelity, players were instructed that they could move around freely during the task, rather than be seated and passively respond to the stimuli (see Roca, Williams, & Ford, 2014). Yet, there remain potential limitations in stimulus-response compatibility, as the participants made their predictions by pressing a button; they did not have to carry out a defensive action as they would in a match. As such, the task may have failed to preserve the functional coupling between perception and action, which may limit the real-world applications of our findings (Araújo et al., 2006; Van der Kamp et al., 2008). Furthermore, the stable contextual priors used in this study were restricted to the action tendencies of an opponent in possession. As stable contextual priors may come in different forms (for a review, see Williams & Jackson, 2019), we encourage researchers to examine how different types of contextual priors that are likely to be present during a soccer match (e.g., game state and opponent action tendencies) are weighed and integrated with each other and evolving kinematic information during anticipation. It is also of note, that while the participants were female soccer players, the test stimuli involved male soccer players. To our knowledge, we have no reason to believe that gender-specific features (e.g., technical execution of a skill or tactical behaviour) would have influenced the anticipation process – at least not to a greater degree than the variability present across different players of the same gender would have done. However, we acknowledge that research is required to examine this issue and identify any related factors concerning the correspondence between the stimuli and the performance environment (Pinder et al., 2011).

It is worth highlighting that there might have been a learning effect over the test session of 120 trials, as players could have used information acquired in preceding conditions, and the performance feedback, to facilitate learning. However, previously, researchers have reported that the provision of performance feedback is necessary to keep participants motivated to stay engaged with the task throughout the test session (Gredin et al., 2019). Moreover, to mitigate potentially confounding learning and carryover effects across conditions we employed a randomised and counterbalanced within-participant design, which is a commonly used approach when examining the impact of various informational conditions in sport (cf. Gray, 2009; Jackson et al., 2006; Runswick et al., 2018b). Additionally, to avoid any potential familiarity effects, the order in which the trials were presented with and without explicit contextual priors was randomised (cf. Gredin et al., 2018).

In summary, our novel findings provide new insights into how skilled soccer players use explicit contextual priors and kinematic information during anticipation. The impact of explicit contextual priors is contingent on the reliability of available kinematic information, as well as that of the priors themselves. Namely, more weight is given to sources of information associated with relatively lower uncertainty, and vice versa. Findings provide support for the notion that athletes employ Bayesian reliability-based strategies when integrating evolving visual information and contextual priors pertaining to an opponent's action tendencies during anticipation (see Loffing & Cañal-Bruland, 2017). We encourage researchers to continue to explore the merits of Bayesian probabilistic models when trying to predict anticipatory behaviours in sport.

Disclosure of interest

The authors report no conflict of interest.

ORCID

N. Viktor Gredin http://orcid.org/0000-0003-2151-8928

References

Araújo, D., Davids, K., & Hristovski, R. (2006). The ecological dynamics of decision making in sport. *Psychology of Sport and Exercise*, *7*(6), 653–676. https://doi.org/10.1016/j.psychsport.2006.07.002

Batterham, A. M., & Hopkins, W. G. (2006). Making meaningful inferences about magnitudes. *International Journal of Sports Physiology and Performance*, *1*(1), 50–57. https://doi.org/10.1123/ijspp.1.1.50

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*, *33*(3) 389-596. https://doi.org/10.1080/02699931.2018.1464434

Brouwer, A. M., & Knill, D. C. (2009). Humans use visual and remembered information about object location to plan pointing movements. *Journal of Vision*, *9*(1), 1–19. https://doi.org/10.1167/9.1.24

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*, 1518. https://doi.org/10.3389/fpsyg.2015.01518

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*. Routledge.

Cumming, G. (2014). The new statistics: Why and how. *Psychological Science*, *25*(1), 7–29. https://doi.org/10.1177/0956797613504966

Dror, I. E., Péron, A. E., Hind, S.-L., & Charlton, D. (2005). When emotions get the better of us: The effect of contextual top-down processing on matching fingerprints. *Applied Cognitive Psychology*, *19*(6), 799–809. https://doi.org/10.1002/acp.1130

Ericsson, K. A., & Ward, P. (2007). Capturing the naturally occurring superior performance of experts in the laboratory: Toward a science of expert and exceptional performance. *Current Directions in Psychological Science*, *16* (6), 346–350. https://doi.org/10.1111/j.1467-8721.2007.00533.x

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

Gray, R. (2009). How do batters use visual, auditory, and tactile information about the success of a baseball swing? *Research Quarterly for Exercise and 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*, *24*(4), 509-520. https://doi.org/10.1037/xap000074

Gredin, N. V., Broadbent, D. P., Findon, J. L., Williams, A. M., & Bishop, D. T. (2020). The impact of task load on the integration of explicit contextual priors and visual information during anticipation. *Psychophysiology*, *57* (6), 1–13. https://doi.org/10.1111/psyp.13578

Gredin, N. V., Broadbent, D. P., Williams, A. M., & Bishop, D. T. (2019). Judgement utility modulates the use of explicit contextual priors and visual information during anticipation. *Psychology of Sport and Exercise*, *45*(July), 101578. https://doi.org/10.1016/j.psychsport.2019.101578

Helm, F., Cañal-Bruland, R., Mann, D. L., Troje, N. F., & Munzert, J. (2020). Integrating situational probability and kinematic information when anticipating disguised movements. *Psychology of Sport and Exercise*, *46* (January), 101607. https://doi.org/10.1016/j.psychsport.2019.101607

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

Hopkins, W. G. (2020). Sample sizes for various inferential methods. *Sportscience*, *24*(24), 17–27. sportsci.org/2020/MBDss.htm

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*(1), 49–68. https://doi.org/10.1123/jsep.28.1.49

Jackson, R. C., Barton, H., & Bishop, D. T. (2020). Knowledge is power? Outcome probability information impairs detection of deceptive intent. *Psychology of Sport and Exercise*, *50*(September), 101744. https://doi.org/10.1016/j.psychsport.2020.101744

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

Mann, D. T., Williams, A. M., Ward, P., & Janelle, C. M. (2007). Perceptual-cognitive expertise in sport : A meta-analysis. *Journal of Sport & Exercise Psychology*, *29*(4), 457–478. https://doi.org/10.1123/jsep.29.4.457

Miyazaki, M., Nozaki, D., & Nakajima, Y. (2005). Testing Bayesian models of human coincidence timing. *Journal of Neurophysiology*, *94*(1), 395–399. https://doi.org/10.1152/jn.01168.2004

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

Neyman, J., & Pearson, E. S. (1933). On the problem of the most efficient tests of statistical hypotheses. *Philosophical Transactions of the Royal Society Lond*, *231*, 289–337.

Pinder, R. A., Davids, K., Renshaw, I., & Araújo, D. (2011). Representative learning design and functionality of research and practice in sport.

Journal of Sport & Exercise Psychology, *33*(1), 146–155. https://doi.org/10.1123/jsep.33.1.146
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
Roca, A., Williams, A. M., & Ford, P. R. (2014). Capturing and testing perceptual-cognitive expertise: A comparison of stationary and movement response methods. *Behavior Research Methods*,*46*(1), 173–177. https://doi.org/10.3758/s13428-013-0359-5
Runswick, O. R., Roca, A., Williams, A. M., McRobert, A. P., & North, J. S. (2018a). 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
Runswick, O. R., Roca, A., Williams, A. M., Bezodis, N. E., Mcrobert, A. P., & North, J. S. (2018b). The impact of contextual information and a secondary task on anticipation performance: An interpretation using cognitive load theory. *Applied Cognitive Psychology*, *32*(2), 141–149. https://doi.org/10.1002/acp.3386
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
Triolet, C., Benguigui, N., Le Runigo, C., & Williams, A. M., . . (2013). Quantifying the nature of anticipation in professional tennis. *Journal of Sports Sciences*, *31*(8), 820–830. https://doi.org/10.1080/02640414.2012.759658 .
van der Kamp, J., Rivas, F., van Doorn, H., & Savelsbergh, G. J. P. (2008). Ventral and dorsal system contributions to visual anticipation in fast ball sports. *International Journal of Sport Psychology*, *39*(2), 100–130.
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
Ward, P., Hodges, N. J., Starkes, J. L., & Williams, M. A. (2007). The road to excellence: Deliberate practice and the development of expertise. *High Ability Studies*, *18*(2), 119–153. https://doi.org/10.1080/13598130701709715
Wasserstein, R. L., Schirm, A. L., & Lazar, N. A. (2019). Moving to a world beyond “p < 0.05”. *American Statistician*, *73*(sup1), 1–19. https://doi.org/10.1080/00031305.2019.1583913
Wilkinson, M. (2014). Distinguishing between statistical significance and practical/clinical meaningfulness using statistical inference. *Sports Medicine*, *44*(3), 295–301. https://doi.org/10.1007/s40279-013-0125-y
Williams, A., & Davids, K. (1998). Visual search strategy, selective attention, and expertise in soccer. *Research Quarterly for Exercise and Sport*,*69*(2), 111–128. https://doi.org/10.1080/02701367.1998.10607677
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. (2019). 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*, *42*(August), 16–24. https://doi.org/10.1016/j.psychsport.2018.11.014
Winter, E. M., Abt, G. A., & Nevill, A. M. (2014). Metrics of meaningfulness as opposed to sleights of significance. *Journal of Sports Sciences*, *32*(10), 901–902. https://doi.org/10.1080/02640414.2014.895118
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