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Anticipation in sport: Fifty years on, what have we learned and what research still needs to be undertaken?

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ABSTRACT

The ability to anticipate what will happen next is critical to performance in many sports as well as other professional domains. We review progress made in our scientific understanding of this topic since the seminal work conducted some 50 years ago. We highlight advances in methods and measures and identify the different perceptual-cognitive skills that have been identified by researchers as playing a pivotal role in anticipation. We examine how these perceptual-cognitive skills are used in a dynamic and interactive manner to facilitate anticipation, as well as how their importance varies due to the stress placed upon athletes by anxiety and fatigue. We summarise the impact of existing research on the development of training programs that facilitate skill acquisition. Finally, we provide some suggestions for future research in this area. We encourage continued growth in recent research exploring the role of contextual information in anticipation and present suggestions as to how the translational impact of this work can be increased in applied domains.

The ability to anticipate what an opponent is going to do next is crucial in sports, particularly where significant time pressures exist (Williams & Jackson, 2019; Williams, Casanova, & Toledo, 2018). For example, the return of serve in tennis, table tennis, and badminton, batting in baseball and cricket, the penalty kick, flick or throw in soccer, field hockey, and handball respectively, are all situations in which the ability to anticipate may help the athlete overcome extreme spatio-temporal constraints. Those athletes who anticipate successfully are described as being able to 'read the game well', 'demonstrate superior game intelligence' or appearing as if 'they have all the time in the world' (Williams, Broadbent, Murphy, & Janelle, 2018; Williams, Ford, Hodges, & Ward, 2018). In light of the perceived importance of anticipation, not only in sport, but in other high-performance domains such as the military, aviation, and law enforcement, the phenomenon has attracted significant research interest over the last 50 years (Williams, Ford, Eccles, and Ward, 2011).

The first published study on anticipation in sport actually coincides nicely with the launch of FEPSAC. In 1968, a certain M. L. Enberg defended a PhD thesis at Purdue University, Indiana that focused on perceiving object directionality in tennis. However, it was a decade later in Europe, that research on this topic truly came to the fore with publication of the seminal research paper by Jones and Miles (1978), based at the University of Bangor, in North Wales in the UK. Jones and Miles (1978) were the first authors to use the film-based, temporal occlusion paradigm. Using the limited technology available at the time, they presented participants with 16 mm filmed images of an opponent serving in tennis and asked them to anticipate where the ball would land. Participants responded by inserting a cross in one of three response boxes on a scaled, schematic representation of a tennis court. A repeated-measures design was employed whereby each serve was presented under one of three viewing conditions, with trials being edited (i.e., occluded) either 42 ms before, at, or 335 ms after the opponent's racket made contact with the ball. Participants were required to make a judgment based on information available up to the point of occlusion, which in the pre-ball-racket contact conditions meant that judgments had to be made based on advance (i.e., pre ball flight) postural cues only. The expert tennis players were more accurate in making anticipation judgments when compared to less expert players, particularly in the earliest occlusion conditions, with accuracy scores being significantly above chance (i.e., > 33%) across all viewing conditions. The expert tennis players were able to pick-up advance (postural) cues from the opponent ahead of ball-racket contact in order to enable them to successfully anticipate where the ball was likely to land on their side of the court.

The approach used by Jones and Miles (1978) was ahead of its time and it was not until another decade had passed that this field of research really mushroomed in regards to its level of interest among scientists. Bruce Abernethy played an integral role in helping to fuel

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this growth with a series of follow-up studies using film-based occlusion methods in the mid-1980's (e.g., Abernethy, 1988; Abernethy & Russell, 1984, 1987), and he may therefore be viewed as the founding father of modern day research on this phenomenon. He was also the first author to use the spatial occlusion paradigm where different sources of information were painstakingly edited on each individual image to create different event occlusion conditions (Abernethy & Russell, 1987). This paradigm allowed researchers to identify the most informative cues by ascertaining the extent of the decline in judgment accuracy relative to a non-occluded control condition. The advent of digital video and image editing software allowed researchers to occlude or remove information sources quickly and precisely (Jackson & Mogan, 2007; Loffing & Hagemann, 2014) and to combine both the spatial and temporal occlusion paradigms to more fully address questions related to 'what' information is important and 'when' this is extracted from the display (Müller, Abernethy, Eid, McBean, & Rose, 2010). This work did much to identify the individual sources of information used during anticipation; however, the importance of other perceptual-cognitive skills in the process, such as pattern recognition, the use of situational probabilities and the role of situation-specific context, received far less attention (Williams, Fawver, Broadbent, Murphy, & Ward, in press).

In this article, we have two main aims. First, we briefly overview key research findings that have emerged since these seminal studies with a view to providing the reader with a historical picture of how the field has evolved, perhaps in keeping with the corresponding growth over recent decades in both the sport sciences and sport psychology more broadly. Second, we focus our efforts on predicting what the future holds in this area of study. We attempt to identify some questions that remain unanswered and illustrate areas that merit more investigative effort. It is not our intention to present a detailed overview of all work on this topic; neither do we imply that the areas highlighted are the most important as far as this field of study is concerned. Our aim is merely to highlight a few avenues that we feel are important and where the field would benefit from additional experimental work over coming years. We are unable to provide a detailed overview of all areas related to this topic and apologize in advance for neglecting interesting topics related to, amongst others, embodied cognition and motor resonance, perception-action coupling, as well as a growing body of research focusing on the neural mechanisms underpinning anticipation. The reader is directed to an alternative outlet for more comprehensive reviews of these topics (Williams & Jackson, 2019).

1. A review of key findings: what we know already about anticipation

1.1. A number of key perceptual-cognitive skills underpin effective anticipation

The seminal work by Jones and Miles (1978) highlighted the importance of picking up postural cues or biological motion information from the movements of an opponent (and potentially teammates) when attempting to anticipate what she/he will do next. The proposal is that skilled anticipators are better able to extract information distributed globally across the body, rather than relying on a single isolated or local information cue or source (Huys et al., 2009; Smeeton, Hüttermann, & Williams, 2019). There is evidence that skilled anticipators are better attuned to information distributed broadly across the body and that for throwing or striking actions this information is processed in a proximal-to-distal manner that reflects the sequential recruitment of movement segments (Abernethy, Zawi, & Jackson, 2008). It appears that experts are particularly sensitive to sources of information close to the end effector, such as the arm and racket in tennis (Huys, et al., 2009), and the hand in cricket spin bowling (Müller, Abernethy, & Farrow, 2006).

However, the use of early visual information to anticipate an actor's intentions leaves observers vulnerable to deception and the actor often exploits this issue during competition. In many interactive sports, deceptive actions are commonplace and over the last decade or so researchers have studied the ability to judge deceptive intent (Jackson, Warren, & Abernethy, 2006; for a review see Jackson & Cañal-Bruland, 2019). These researchers have shown that differences between high and less-skilled performers are sometimes much larger for judgments of deceptive actions than genuine actions (Brault, Bideau, Kulpa, & Craig, 2012; Wright & Jackson, 2014). Furthermore, skill-based differences in judging an action to be genuine or deceptive (response bias) have been observed in handball (Cañal-Bruland, & Schmidt, 2009), savate (Ripoll, Kerlirzin, Stein, & Reine, 1995), and soccer (Jackson, Barton, Ashford, & Abernethy, 2018). This finding implies that the ability to differentiate genuine and deceptive actions may be a key determinant of expertise in anticipation. Many of the questions that apply to anticipation of genuine actions also relate to judgments of deceptive actions. For example, Brault, Bideau, Craig, and Kulpa (2010) found that differences in distributed sources of information (outer foot displacement, lower trunk yaw, head yaw, upper trunk yaw, upper trunk roll), and center of mass displacement, differentiated a genuine change in direction from a deceptive sidestep action, with experts being were more attuned than less-skilled players to the 'honest' center of mass displacement signal (Brault et al., 2012).

While the large majority of researchers have focused on identifying the key cues (i.e., what) and the time (i.e., when) they are extracted from the display, other perceptual-cognitive skills have been identified as playing a role in anticipation. One important skill is the ability of athletes to identify patterns in evolving sequences of play. Following on from early research in chess using the recall and recognition paradigms (e.g., Chase & Simon, 1973), the typical approach has been to show athletes video footage of offensive sequences of play from the perspective of a defensive player and then to ask observers to either recall players' positions at the end of the sequence or to make a judgment as to whether the sequence was presented in an earlier viewing phase. Skilled athletes are more accurate at both of these tasks leading to the suggestion that the ability to identify a pattern early in a sequence enables the perceiver to anticipate what will happen at the end of the action (see North & Williams, 2019). The seminal paper was published by Allard, Graham, and Paarsalu (1980), whereas subsequently several researchers have extended our understanding of pattern recognition using team sports such as soccer (Williams & Davids, 1995; North, Ward, Ericsson, & Williams, 2011, 2017), basketball (Gorman, Abernethy, & Farrow, 2012), and field hockey (Smeeton, Ward, & Williams, 2004). While the findings emerging from this body of research have been consistent in identifying skill-based differences in pattern recall and recognition, more recently efforts have shifted towards identifying the underlying processes and mechanisms involved and the extent to which the skill(s) is related to anticipation or merely a by-product of exposure to the performance domain (see North et al., 2011; Williams, North, & Hope, 2012).

Another perceptual-cognitive skill that has been identified as a key component of anticipation is the ability to prioritize the importance of unfolding events in the display. Alain and Proteau (1980) were the first to report that athletes assign actual probabilities to likely events as a means of reducing uncertainty. More recently, others (e.g., Belling, Suss, & Ward, 2015; Ward, Ericsson, & Williams, 2013) have highlighted that skilled athletes are more accurate in their predictions of what will happen next, are better at identifying task-relevant options, while ignoring irrelevant ones, and are more accurate in rank ordering those options. The assumption is that the expert's more accurate mental representations of the potential alternative courses of action that an opponent might take are positively associated with superior anticipation. In sum, skilled athletes are able to assign a hierarchy of probabilities based on likely event scenarios, minimizing uncertainty and reducing cognitive load.

A third well-documented finding is the ability of expert athletes to use the visual system in a different, and potentially more effective manner, when scanning and extracting information from the display.

Numerous researchers have used portable eye-tracking systems to record gaze behaviors as athletes attempt to anticipate in laboratory and field settings (Mann, Causer, Nakamoto, & Runswick, 2019; Williams, Janelle, & Davids, 2004). Typically, skill-based differences in gaze behaviors are recorded, with experts fixating on different areas of the display, scanning the display more systematically and effectively as evaluated by their superior performance on the task. However, the most optimal search behavior, as determined by the number and duration of fixations, has been shown to be task and context specific (Roca, Ford, McRobert, & Williams, 2013). In some instances skill-based differences arise due to the quality of information extracted (per fixation) or the more effective use of the para-fovea or visual periphery rather than in gaze behavior per se (Williams & Davids, 1998). Several distinct strategies have been identified to illustrate how experts can change the focus of attention without moving the eyes using, for example, visual pivots, gaze anchors, and foveal spots (see Vater, Williams, & Hossner, 2018).

1.2. Perceptual-cognitive skills vary in importance and interact dynamically

A significant advancement over the last decade has been the shift away from considering anticipation as being based on a single perceptual-cognitive skill (notably cue usage) towards a greater emphasis on examining how different perceptual-cognitive skills vary in importance and interact dynamically during skilled anticipation (Roca & Williams, 2017; Williams, 2009). A framework is presented in Fig. 1 to illustrate how athlete (e.g., emotional, cognitive, and motor abilities), task (e.g., situation, context), and environmental (e.g., lighting, weather) constraints influence the dynamic interactions between the perceptual-cognitive skills underpinning anticipation.

The schematic highlights the fact that gaze behaviors and ultimately anticipation are driven by the complex interactions between several different perceptual-cognitive skills including cue usage, pattern recognition, and the use of higher-order cognitive factors related to context and situational/event probabilities. The proposal is that the importance of these skills varies from moment to moment depending on a range of factors including the strengths and weaknesses of individual athletes, the constraints of the task and environmental conditions. Roca et al. (2013) were the first to examine how the relative importance of the different perceptual-cognitive skills interact during anticipation in a single study. Using a film-based anticipation task involving offensive scenarios presented using the viewing perspective of a central defender in soccer, they manipulated the task constraints to include sequences that either started with the ball in the opposing team's half of the field of play (i.e., far task) or nearer to the observers penalty area (i.e., near task). Gaze behaviors and think-aloud verbal reports were gathered as players viewed the different sequences. Players were required to anticipate what the player in possession of the ball would do at the end of each short sequence (i.e., pass, shoot, dribble).

As expected, skill-based differences in gaze behaviors were reported on the task, with the specific strategy employed interacting with the type of task presented. In the far task, the skilled players used more fixations of shorter durations to more disparate areas of the display when compared to the near task, implying a broader allocation of foveal attention. In contrast, during the near task, the skilled players spent more time fixating on the player in possession of the ball, with a reduction in the number of fixations, the number of locations fixated, and an increase in fixation durations when compared to the far task scenarios, implying greater use of peripheral vision. These differences in gaze behaviors were less pronounced in the less-skilled players, who were more likely to spend longer periods of time 'ball watching'. The most important findings emerged from the verbal reports. In the far task, skilled players relied more on thought processes related to pattern recognition, whereas in the near task there was greater reliance on postural cues and situational probabilities. The verbal report data are presented in Fig. 2. These data nicely illustrate the dynamic interactions between the different perceptual-cognitive skills when anticipating, as well as how their importance differ as a function of the task constraints (cf., Vaeyens, Lenoir, Williams, Mazyn, & Phillppaerts, 2007a; 2007b).

In similar vein, it has been reported that emotions such as anxiety as well as other stressors like workload/fatigue impact on the manner in which information is processed. Several published papers report

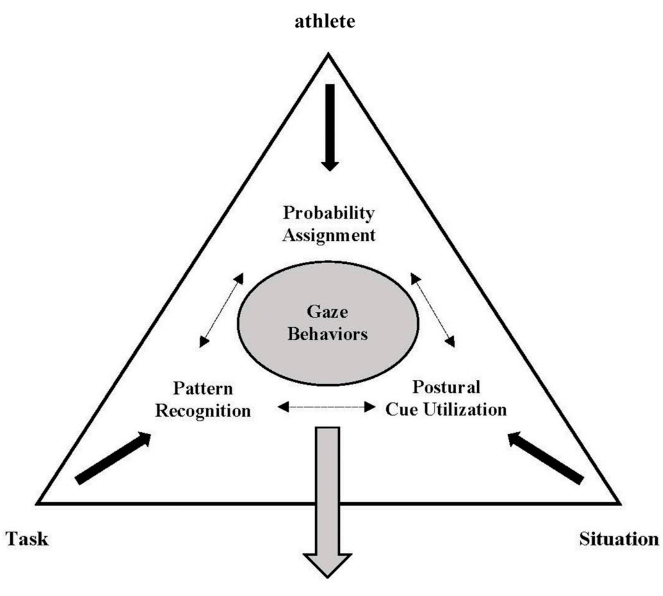

Fig. 1. The potential interaction between perceptual-cognitive skills and constraints during anticipation judgments (from Williams, 2009).

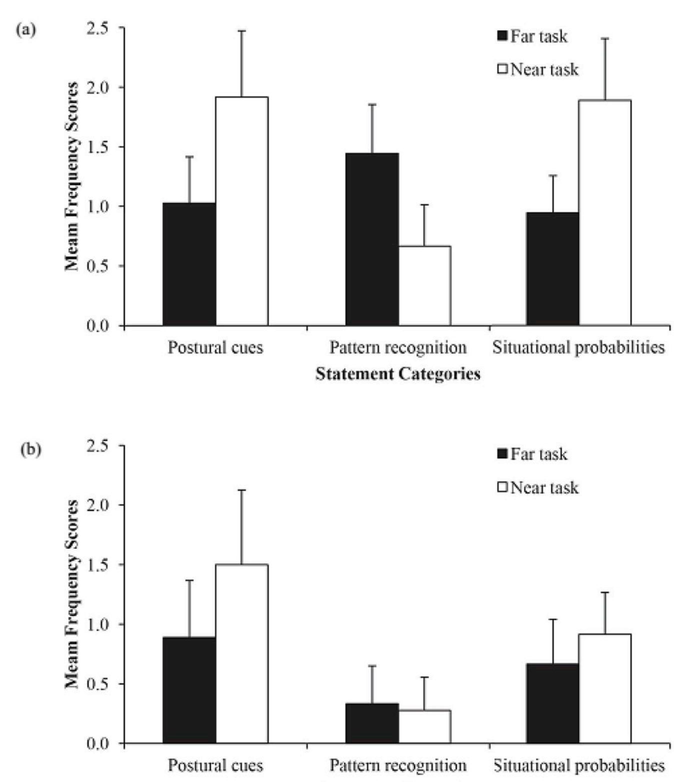

Fig. 2. The mean frequency scores (SD) per trial of verbal statements relative to the perceptual-cognitive skills referred to by skilled (a) and less-skilled (b) soccer players under near and far task constraints (data from Roca et al., 2013).

substantive changes in gaze behaviors when attempting to anticipate with increasing levels of anxiety (Vater, Roca, & Williams, 2015; Williams & Elliott, 1999), fatigue (Casanova et al., 2013), and workload (Vickers & Williams, 2007). Moreover, Cocks, Jackson, Bishop, and Williams (2016) reported that the importance of the different perceptual-cognitive skills may change with increasing levels of anxiety, with potentially greater reliance being placed on low- (such as postural cue usage) rather than high-level (such as shot sequencing and court positioning) cognitive processes when anxious. Such a shift in the prioritization of information would align with theories that imply less emphasis on top-down control when anxious (Eysenck, Derakshan, Santos, & Calvo, 2007).

1.3. How scientists have attempted to develop training programs to enhance anticipation

Scientific investigations focusing on how anticipation may be trained are less apparent in the literature, perhaps because such studies typically need to be preceded by research that examines what should be trained rather than how. Moreover, the relative paucity of research likely reflects the difficulty involved in undertaking such training studies, given the need for control, placebo, and intervention groups, extended acquisition periods, and transfer and retention tests. Although there are published reports that focus on training perceptual-cognitive skill in sport dating back to the 1960s (e.g., Haskins, 1965), the paper by Burroughs (1984) likely marks the seminal work on this specific topic. Burroughs (1984) used a film-based paradigm in which participants viewed pitches from a batter's perspective and were required to anticipate the intended location of the pitch. During training, participants were presented filmed pitches that were occluded shortly after the pitcher released the ball. In a follow-up presentation, the entire pitch was then viewed and feedback provided indicating which part of the plate the ball would travel over. An improvement in performance on the film-based anticipation test was observed pre-to post-intervention.

Over the next decade there followed a trickle of related studies designed to examine whether and how anticipation may be trained (for historical reviews, see Abernethy, Wood, & Parks, 1999; Williams, Davids, & Williams, 1999). A combination of video-based and on-court training methods were used with an emphasis on highlighting relevant sources of information, offering various practice opportunities and presenting feedback on performance. However, while the vast majority of studies report positive training effects, much of the research continues to be characterized by shortcomings in experimental design. These shortcomings included the absence of adequate control and placebo groups, relatively short acquisition periods, no recording of process tracing measures such as gaze behaviors to examine exactly what changes with training, and inadequate, or missing, retention and/or transfer tests. While several of these limitations have been addressed to varying extents in more recent work (see Broadbent, Causer, Ford, & Williams, 2015; Broadbent, Causer, Williams, & Ford, 2014), there remain relatively few published studies using well-designed and controlled interventions.

The vast majority of existing papers have focused exclusively on the training of cue usage, with hardly any research focusing on the trainability of other perceptual-cognitive skills such as pattern recognition (for an exception, see North, Hope, & Williams, 2017) and the use of contextual information (for an exception, see Williams, Herron, Ward, & Smeeton, 2008). Similarly, no reports exist where researchers have attempted to train athletes to exploit the interactions between the different perceptual-cognitive skills or whether any improvements in performance during acquisition are retained over extended periods of time (i.e., weeks and months as opposed to hours or days; for an exception, see Abernethy, Schorer, Jackson, & Hagemann, 2012). Perhaps most importantly, our efforts to create realistic transfer tests have been limited, with such tests normally replicating very closely the conditions that existed during training (Williams et al., in press). For example, interventions that train the pick-up of postural cues are tested under transfer conditions where athletes are required to anticipate based solely on postural cues in the absence of context or access to other perceptual-cognitive skills. Similarly, only a small handful of published reports exist where the stressors that exist during competition such as anxiety and fatigue are replicated in the transfer test used to evaluate the effectiveness of the training program (for exceptions, see Alder, Ford, Causer, & Williams, 2016; Smeeton, Williams, Hodges, & Ward, 2005). Such limitations may explain the continued absence of well-designed and systematic training programs in applied, high-performance sport settings (Williams, Causer, Ford, Logan, & Murray, 2012).

2. Some suggestions for future research: what we need to find out

2.1. What role does context play in anticipation?

Although a few older papers exist (e.g., Paull & Glencross, 1997), recent years have seen increased interest in identifying the role of context in anticipation and how such information may be used in conjunction with other perceptual-cognitive skills such as postural cues. Abernethy, Gill, Parks, and Packer (2001) reported one of the earliest studies focusing on the role of context in anticipation. They showed that skilled squash players were able to accurately anticipate an opponent's shot well before (i.e., > 620 ms) contact was made with the ball, with performance being above chance levels. Since the players were anticipating well before ball-racket contact, it implies that judgements were being made in advance of the availability of postural cues around ball racket contact. Similarly, Triolet, Benguigui, Le Runigo, and Williams (2013) demonstrated using video-based, time-use analysis of rallies involving the top-10 male tennis players in the world that the vast majority of observable anticipation behaviors were made in advance (> 320 ms) of ball-racket contact by the opponent. While these studies do not dismiss the importance of picking-up postural cues from an opponent's movements as the moment of ball-racket contact approaches, perhaps as a source of confirmatory information, they do demonstrate that in some instances alternative sources of information may be guiding the anticipation process (cf., Loffing & Hagemann, 2014). The key question therefore is in the absence of postural cues and well-ahead of the critical moment (e.g., ball-racket contact) what alternative sources of information are players using to anticipate what an opponent will do next?

Over recent years researchers have identified several contextual factors that impinge on anticipation including the action tendencies of opponents (Barton, Jackson, & Bishop, 2013; Gredin, Bishop, Broadbent, Tucker, & Williams, 2018; Mann, Schefers, & Canal-Bruland, 2014; Navia, van der Kamp, & Ruiz, 2013), the positioning of players on the field of play (Loffing & Hagemann, 2014; Loffing, Solter, Hagemann, & Strauss, 2016; Murphy et al., 2016), the sequence or order of action sequences (Loffing, Stern, & Hagemann, 2015; Murphy, Jackson, & Williams, 2018) and the score within the match (Farrow & Reid, 2012; Runswick, Roca, Williams, Bezodis, & North, 2018). The various sources of contextual information described above are much more diverse and exhaustive than the more specific use of situational or event probabilities to guide anticipation. The latter may therefore be viewed as one specific source of contextual information. Moreover, all of these contextual information sources may be picked up dynamically as the action unfolds, with experts being adept at developing and updating cognitive models 'on the fly', enabling them to move from a reactive to a more anticipative response mode (McRobert, Ward, Eccles, & Williams, 2011).

In a recent program of work, Murphy et al. (2016) demonstrated that skilled tennis players are able to accurately anticipate an opponent's stroke even when postural cues are removed from the display. They employed data gathered via Hawkeye to create animations of rallies in tennis. The two players were presented as cylinders and the images included the court markings and the ball. However, all postural cues and information emanating from the racket, as well as background and structural information, where removed from the action sequences. While a decrement in performance accuracy was reported in the animated condition when compared to film-based presentations of the same rallies, the skilled players retained their superiority over less skilled counterparts, with their accuracy scores in the animated condition being well-above chance levels.

In a series of follow ups involving various experimental manipulations of the animated sequences, it was reported that the positions of the players on the court, the relative movements of the players and the ball, shot sequencing and the angles between the players and various court markings such as the tram or sidelines and baseline all contributed to successful anticipation to varying degrees (Murphy, et al., 2018; Murphy, Jackson, & Williams, 2019a, 2019b). In many instances these sources of contextual information may be the minimal essential information needed for successful anticipation, with potentially later-arising kinematic information from the player's actions around ball-racket contact being confirmatory in nature (Müller & Abernethy, 2012; Triolet et al., 2013). A suggestion is that while access to contextual information helps to constrain the action possibilities considered by the perceiver the later emergence of postural cues further decreases the number of relevant shot options in a funnel-like manner (Müller & Abernethy, 2012; Murphy et al., 2019a).

As yet, only a few researchers have explored how access to contextual information may interact with the availability of postural cues to facilitate (or hinder) anticipation. In one study, Barton et al. (2013) manipulated the situational probability information available to football players as they judged whether an opponent would take the ball to the left or right. On half the trials, the player made a genuine move to the left or right and on the remaining trials executed a deceptive step-over. Before each trial, the probability of the player taking the ball to the left/right (expressed as a percentage) was presented on screen, as 50-50, 67–33, or 83–17. Relative to the 50-50 condition, the 'cost' to response accuracy when action outcomes were incongruent with expectations was greater than the 'benefit' of congruent information. This difference was greater for deceptive actions than genuine actions, suggesting that appropriately aligned high probability values can enhance the deceptive quality of a fake movement.

Runswick, Roca, Wililams, Bezodis, and North (2018) examined the effect of contextual information using a film-based simulation of a cricket batting task in which participants received information relating to game score, the number of overs bowled, the stage of the game (i.e., deliveries remaining), and the number of wickets left. Field placings were highlighted on a schematic representation of the pitch. Footage was then presented of bowlers under each of four different occlusion conditions. In one condition, participants were only presented with the contextual information (no bowler presented). In a second condition, the trial was occluded mid-way through the bowler's run-up, whereas in another condition the clips were occluded just prior to ball release. In a final condition, the clip was occluded 80 ms after ball release. The amount of contextual information presented remained constant across all four conditions.

Skilled batters recorded higher accuracy scores across all conditions when compared with less-skilled players. While performance improved in line with the amount of kinematic information presented, the skilled players were more accurate than chance even in the condition where only the context was presented. Verbal report data collected retrospectively after each clip revealed that the skilled batters progressively increased their reliance on kinematic information in the later occlusion conditions. This shift in reliance on different sources of information is nicely illustrated in Fig. 3.

The figure highlights how the number of verbalizations relating to different sources of information changes over time. However, in this study, the information presented through context and the increasing availability of kinematic information as the trial progressed always implied that the outcome would be consistent (i.e., congruent),

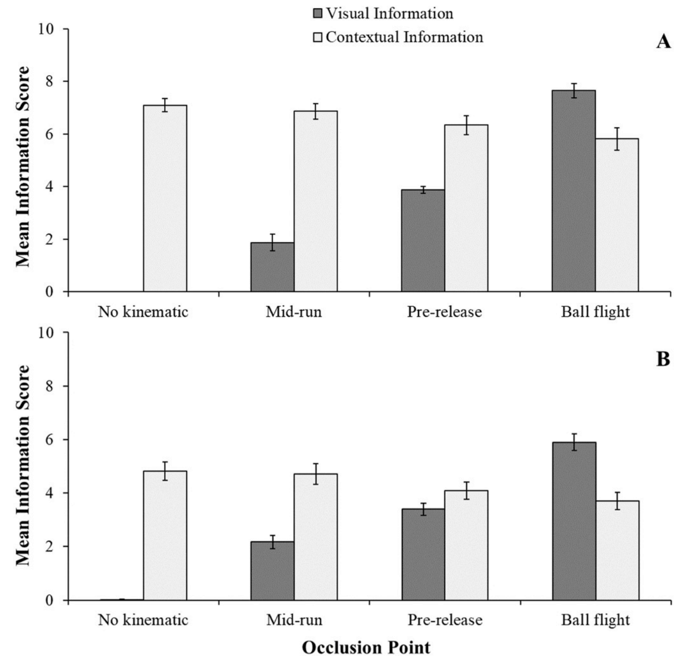

Fig. 3. The mean number of verbalized information sources highlight by (A) skilled and (B) less-skilled batters relating to kinematic/visual (bowler's body and ball flight) and contextual (sequence, game situation and field setting) information sources across the four occlusion conditions (data from Runswick et al., 2018).

irrespective which source of information was prioritized, leading to progressive improvements in accuracy. Yet, in sport, it is sometimes the case that these two sources of information may be incongruent, with the two sources of information suggesting that different outcomes may arise, therefore requiring athletes to prioritize one source over the other. So, how do athletes respond in such instances?

Runswick, Roca, Williams, McRobert, and North (in press) using the same cricket task as described above reported that when the outcome suggested by the contextual information matched or was congruent with that proposed by the kinematic information error rates were very low. In contrast, when these two sources of information were incongruent, the error rates increased markedly, particularly in the skilled group. The authors suggested that skilled players may be more easily deceived by the presentation of incongruent information, potentially due to a process of confirmation bias such that they are more likely to seek out information that confirms rather than rejects their initial perceptions (cf., Loffing et al., 2015).

The availability of contextual information can therefore either positively or negatively impact on anticipation, depending on the level of congruence that exists between the different sources of information (cf., Gray, 2015, Loffing et al., 2015; Mann, Schaefers, & Cañal-Bruland, 2014). However, in a recent extension, Gredin et al. (2018) reported that in a 2 vs. 2 film-based, anticipation task skilled soccer players were able to continuously update their expectations by effectively integrating information relating to an opponent's action tendencies with the emerging display information, enabling them to avoid confirmation bias and to prioritize the most relevant information at any given moment in time. Clearly, more research is needed to increase our understanding of how information relating to context may be integrated with emerging kinematic information in a dynamic manner (cf., Cañal-Bruland & Mann, 2015; Gray & Cañal-Bruland, 2018). Moreover, the extent to which skilled and less-skilled athletes are affected differentially by the level of congruence remains an area for investigation. The outcome of such research should have significant impact on the design of protocols to test anticipation, as well as illuminating how best to develop training programs that enhance anticipation and reduce the risk of deception in sport (Güldenpenning, Kunde, & Weigelt, 2017).

Finally, it should be noted that a myriad of different sources of context may be present in the performance setting (Levi & Jackson, 2018). While some of these are dynamic and change rapidly during the course of competition (e.g., the score, time remaining), other sources are more enduring and less transient. These latter sources may include the playing styles preferred by opponents and the performance rankings of athletes. Williams (2000) initially referred to these as specific and generic situational probabilities, respectively, whereas Runswick et al. (2018) coined the terms situation-specific and nonsituation-specific context to discriminate between these two sources of information. In similar vein, Schläppi-Lienhard and Hossner (2015) have differentiated between three broad sources of context, namely, external, situational, and opponent specific. We need to examine how these different sources of contextual information interact with each other and with the availability of kinematic information to facilitate anticipation (and judgments of deceptive intent). Also, as discussed previously, we need to better identify how the importance of these sources of information changes during competition with fluctuations in emotions and workload/fatigue (Cocks et al., 2016).

2.2. How can we create training programs that better facilitate translational impact in applied settings?

The extent to which knowledge generated through perceptual-cognitive training has impacted on practice in high-performance sport remains disappointing. While coaches and practitioners rightly acknowledge the importance of anticipation, there have been few efforts to develop systematic training programs to enhance performance in applied settings. Moreover, the programs that have been applied generally espouse the benefits of generic or non-sport specific training; a notable example being Neurotracker (e.g., see Faubert & Sidebottom, 2012; Romeas, Guldner, & Faubert, 2016). Although limited, if any, well-conducted studies exist to support Neurotracker, its use in high-performance domains is widespread, as highlighted by a recent New York Times article (https://www.nytimes.com/2017/01/04/sports/neurotracker-athletic-performance.html). In contrast, while empirical evidence supporting sport-specific training programs is relatively robust, their use in high-performance sports is not widespread. A proverbial paradox. The relative absence of sport-specific training programs may reflect the inherent difficulty in developing such protocols, which by definition need to be unique to each sport and possibly to different positional roles within these sports (Williams, Ward, Smeeton, & Ward, 2008), making it difficult to develop profitable 'off the shelf' products. Yet, the practical difficulties involved in developing such training programs should not dissuade scientists from continuing to undertake high-quality research to verify their usefulness and elicit how they may best be developed and implemented.

First, efforts are needed to explore the relative benefits of training perceptual-cognitive skills in isolation, as is currently the case, compared to any added benefits that may be gained by training these in combination. Since the skills interact in a dynamic, and possibly an additive, or at least a confirmatory, manner during performance (e.g., see Roca et al., 2013), it would seem crucial to develop training programs that mirror the way in which these skills are used in competition. Part of the problem relates to the manner in which transfer benefits are evaluated. If skills are trained in isolation and then tested in isolation, then the extent of the transfer is likely to be high. However, what if skills are trained in isolation and then tested under conditions in which it is advantageous to use many different perceptual-cognitive skills (e.g., see Roca et al., 2013)? Similarly, training should focus on differentiating genuine and deceptive actions. It is conceivable that training anticipation in isolation will increase susceptibility to deception for actions in which deception is commonplace. To date, few researchers have focused on training perception of deceptive intent, although the preliminary results are promising (see Alsharji & Wade, 2016; Ryu, Abernethy, Park, & Mann, 2018). This sentiment extends to the importance of creating training environments that recreate the same stressors that exist during competition, including appropriate levels of anxiety and fatigue (see Alder, Causer, & Poolton, 2019).

A further extension of this notion is the importance of creating training programs that are not devoid of context. In light of more recent efforts to examine the impact of contextual factors on how athletes search for and pick up other sources of information in the display, it would appear that these interactions need to be recreated in training to optimize transfer of learning (see Broadbent, Ford, O'Hara, Williams, & Causer, 2017). It is crucial to ascertain whether the training effects observed under relatively context-poor conditions remain when performance is assessed under the more context-rich conditions typical of actual competition. Provisional findings suggest that training protocols that better recreate the real-world performance context are more likely to facilitate transfer than those devoid of context (e.g., see Broadbent et al., 2017).

In an effort to better ascertain the sources of contextual information that are important across sports, it may be beneficial for sport psychologists to establish closer links with performance analysts. In recent years, there has been significant growth in the extent to which high-performance athletes rely on performance analysis to quantify and describe opponent behaviors (Memmert, Lemink, & Sampaio, 2017). Yet, while such information may help identify the important sources of contextual information within each sport, this information has yet to be integrated into perceptual training interventions. A potential fruitful area for future research necessitates that performance analysts and sport psychologists work together to better identify how the data routinely gathered by the former may feed into applied interventions developed by the latter (see McRobert & Williams, 2019). A systematic task analysis within each sport should better identify the sources of contextual information that are most crucial to anticipation, providing a more parsimonious approach to developing perceptual-cognitive training programs.

It is tempting to suggest that training protocols that mimic the tight couplings that exist between perception and action in competition may have positive benefits, vis-à-vis based on the notion of specificity of practice. Scientific evidence highlighting the benefits of embedded-cognition (see Mulligan & Hodges, 2019) and more representative task designs (see Dicks, Araújo, & van der Kamp, 2019) would support this notion. However, what is apparent is that the coupling between perception and action need not always be tightly interwoven. For example, contextual information relating to the positions of fielders, the score in the match, and the tendencies of various opponents may not be as tightly linked to immediate action as might be, for example, the couplings between later occurring postural cues and immediate ball flight. While there may in some sports (tasks) be distinct advantages to creating representative task designs that ensure the functional couplings between perception and action are maintained, there may be other sports (tasks) where the need to recreate context may play a more crucial role in facilitating anticipation. Scientists must therefore be cautious in how they interpret and apply the notion of representative task design. A representative design is not merely one that couples together perception and action; our view is that it's more to do with increasing the level of specificity such that practice better matches competition and increases the potential for positive transfer. This emphasis on specificity necessitates a more multi-faceted conceptualization of the notion of representative task design than that is often espoused in the literature (e.g., see Pinder, Davids, Renshaw, & Arujo, 2011). It would appear beneficial to maintain where possible the integrity of the competition setting as a whole, including the context and the levels of stress and fatigue created, rather than merely focusing on maintaining the functional couplings between perception and action. The relative importance of these different facets of representative task design may vary depending on the sport and the specific question under investigation. These notions apply equally to the protocols used for testing as well as training anticipation.

In keeping with the emphasis on creating more sensitive methods and measures, greater efforts are needed to examine not only whether perceptual-cognitive training programs are effective but also what actually changes as a function of practice. We need to examine the efficiency of learning during perceptual training programs as well as their effectiveness (Williams, Fawver, & Hodges, 2017). Process-tracing measures such as gaze recording, EEG, and think-aloud verbal protocols may help elicit changes in the efficiency of learning with different types of training. Moreover, scientists should explore how variability in the processes employed (e.g., gaze behaviors) may be functionally related, or not, to changes in efficiency and effectiveness. Such an approach necessitates a stronger focus on how various types of training may impact in different ways on each athlete, and highlights the need for a more individualized approach to training and how any benefits are evaluated (for an extended discussion, see Williams et al., 2017).

Finally, many of the areas for future research highlighted in recent reviews continue to be relatively unexplored (e.g., see Broadbent, Causer, Williams, & Ford, 2014; Causer, Janelle, Vickers, & Williams, 2012). Only a few researchers have examined whether the relative efficacy of different types of perceptual-cognitive training programs differ with age, skill, and experience. If we set aside the potential shortcomings of training skills in isolation, there continues to be a paucity of research examining whether and how pattern recognition skill or the ability to pick up contextual information may be trained (see North & Williams, 2018; McRobert & Williams, 2019). Moreover, while a moderate amount of research already exists focusing on the relative advantages of different types of instruction (see Le Noury, Farrow, Buszard, & Reid, 2019), the importance of structuring practice appropriately (see Broadbent, Causer, Ford, & Williams, 2019), the potential of virtual reality (see Gray, 2015) and the potential of using imagery to supplement video and on-court training (see Smeeton, Hibbert, Stevenson, Cumming, & Williams, 2013), there remain numerous questions which have yet to be adequately answered.

3. Summary and conclusions

In conclusion, in this article we had two broad aims. First, we wanted to provide a brief glimpse into the past by highlighting some, but by no means all, of the key research findings that have emerged in this area of study over the last 50 years. Second, our aim was to highlight some avenues that merit further scientific investigation. When we reflect back on the research conducted in recent decades it is clear that our methods and measures have advanced significantly, in line with advances in technology, and our understanding of how athletes anticipate has been broadened substantially by identifying the myriad of perceptual-cognitive skills that impact on the process and manner in which these interact dynamically during performance. We are equally pleased by how research undertaken on this topic in sport psychology has positively impacted the measurement of anticipation in numerous other professional domains (see Williams et al., 2011). However, while our knowledge of how to develop training programs to facilitate the more rapid acquisition of the skills underpinning anticipation has improved, the absence of widespread use of such interventions to enhance performance in applied settings remains somewhat disappointing.

In future, greater efforts are needed to extend our knowledge of how athletes can use relevant contextual information in conjunction with the pick-up of postural cues to facilitate anticipation, as well as how they make judgments when these two sources of information are not congruent, suggesting alternative courses of action. Moreover, we need to identify how access to these different sources of information varies in importance across sports, as a function of an athlete's role within each sport, and due to stressors such as anxiety and fatigue. The knowledge that is generated in addressing these questions should ultimately help us to develop more effective perceptual training programs that transfer from training to competition. While acknowledging our disappointment in regards to the impact research in this area has had on applied practice, we continue to believe that this field of study can, and should, have a significant impact on performance enhancement in sport and other professional domains. It remains a paradox that while the ability to anticipate is fundamental to performance in many domains, there remains so much that needs to be discovered to ensure that we continue to advance our capacity as humans to achieve expert performance.

Conflicts of interest

There are no conflicts of interest.

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