The nature of the cognitive advantage: A quarter of a century later

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Abstract

Sport expertise research has flourished within the last quarter of a century, since the publication by Starkes (1987) on the nature of the cognitive advantage in field hockey. In this review article we consider and evaluate how this early research has influenced current paradigms used to study expertise and how conclusions and theories have developed and changed over the past 25 years. In order to provide a framework for selection of studies we focused on studies most related to memory and cognition and inclusion of the original tasks used by Starkes (1987); that is, recall, recognition and decision-making. We consider how more recent tools, typically related to brain processes, impact our understanding of the role of cognition in the expert advantage in sport and more specifically the interrelationships between motor and perceptual-cognitive skills. We end with a summary of some key quotes from the 1987 paper and consider the relevance of these quotes against the backdrop of the reviewed literature.

The nature of the cognitive advantage: A quarter of a century later

Just over a quarter century ago, Starkes (1987) was a pioneer in the study of expert performance and published an influential paper titled, "Skill in field hockey: The nature of the cognitive advantage." The emphasis on the *cognitive* nature of the expert advantage in sport was an important landmark in the conceptualization of skilled sports performance. Twenty-five years on, it is now well established that expert sportspeople are distinguished by a number of perceptual-cognitive skills.

Historically, it was believed that skilled athletes inherited superior nervous systems, which differentiated them from their less skilled peers on a variety of non-specific parameters (Starkes, 1987). Such beliefs catalyzed numerous investigations in the 1970s and 1980s, in which direct links between sport skill and visual-perceptual abilities (e.g., static acuity, dynamic acuity and depth perception) and/or processing abilities (e.g., visual reaction time, nerve conduction time and coincident anticipation ability) were hypothesized. These abilities were considered to reflect the efficiency of the central nervous system (Starkes & Deakin, 1984) and – fittingly named in the burgeoning Computer Age – were classified as components of an individual's "hardware." Contrary to popular belief however, such studies comparing expert and novice sport groups provided little evidence that hardware traits differentiated these groups (e.g., Cockerill, 1981; Sanderson, 1981; Starkes & Deakin, 1984).

A shift in perspective was in order, one that appreciated the acquired, as opposed to innate, nature of the mechanisms underpinning skilled performance. Allard, Graham, and Paarsalu (1980) were the first to address this need for an alternative explanation of superior sport skill. By extrapolating paradigms recently used to qualify expertise in more overtly cognitive tasks (e.g., chess, Chase & Simon, 1973; problem solving in physics, Chi, Feltovich, & Glaser, 1981), Allard et al. (1980) demonstrated that skilled sport performers were akin to “cognitive” experts in their development of advanced domain-specific knowledge. Such acquired cognitive attributes were termed “software” and were quickly identified in a variety of sport-skilled populations (e.g., Allard & Burnett, 1985; Allard et al., 1980; Starkes & Deakin, 1984). However, Starkes (1987) recognized that this early body of research was limited in terms of sample size, a common challenge when investigating experts, the number of task performance measures per study and comparisons between hardware and software traits in the same study.

In 1987, Starkes was the first to take a multi-task approach and assess a range of hardware and software attributes within the same sport performers. National, university-varsity and novice (PE majors), field hockey players, were compared on a battery of tests that measured hardware and software abilities. The groups did not differ in terms of hardware (dynamic visual acuity, simple visual reaction time and coincident anticipation time). In contrast, the national players outperformed the varsity and novice players on the software tasks, demonstrating better recall of game-structured (and unstructured) information and more accurate shot predictions both before and after ball impact. We have summarized the data from these software measures in Figure 1; where similar performance on both measures is demonstrated (recall data in bar graph format and prediction data as line graphs). The National players also demonstrated superior complex decision-making (regarding a depicted player’s optimal next move). The message was clear: elite field hockey players were distinguished from less skilled players in terms of their acquired software but not their hardware abilities (see also Allard & Burnett, 1985; Allard et al., 1980; Starkes & Deakin, 1984). Due to this multi-task approach, the relative contributions of these software attributes towards the determination of sport skill level could also be identified. Recall of game-structured information and shot prediction accuracy were shown to significantly predict group membership.

It has now been just over 25 years since Starkes revealed superior domain-specific recall and prediction (i.e., anticipation skill) to be distinguishing features of high achievement in sport. In the years since, concerted research efforts have been dedicated to qualifying and quantifying the subtleties discriminating expert from novice performance on these perceptual-cognitive abilities. In this review, we chart the trajectory of these findings related to experts' superior perceptual-cognitive skills. We focus on research related to recall, recognition and prediction accuracy (i.e., shot or move prediction) that were most relevant to this early work by Starkes and the techniques adopted by her in the 1987 paper. In limiting our review in this manner we do not cover research in sports related to the development of knowledge structures, nor do we review research on experts' visual search behaviours, which gives insight into what visual information guides experts' decisions and prediction accuracy. Readers are directed elsewhere for reviews on these topics (e.g., Abernethy, 1987; Hodges, Huys, & Starkes, 2007; McPherson, 1993; Starkes & Ericsson, 2003; Williams, Davids, & Williams, 1999; Williams, Ford, Eccles, & Ward, 2011).

A quarter of a century ago, and in the majority of the research since, investigators sought to isolate these perceptual-cognitive abilities and investigate them individually. Recently, there have been attempts (based on behavioural, psychophysiological, and neurophysiological methods) to provide evidence of their dynamic and interactive relationship (e.g., Bishop, Wright, Jackson, & Abernethy, 2013; Elferink-Gemser, Visscher, Lemmink, & Mulder, 2004; Reilly, Williams, Nevill, & Franks, 2000; Ward & Williams, 2003). In this review, we synthesize research contributing to this integrative conceptualization and reconsider what it means to talk about the "cognitive" advantage in sport. In particular, we review recent expertise research showing motor system involvement in athletes' decision processes and question what this involvement might mean for the cognitive advantage. In a summarizing section we consider some key quotes from

Starkes (1987) and their relevance for understanding the cognitive advantage in sport today.

Sporting memory: Pattern recall and recognition

Traditional paradigms

The finding that expert athletes demonstrate superior performance on tests of domain-specific memory is consistent and robust. The recall paradigm most commonly used to capture this phenomenon was adapted from the study of expert chess players (e.g., Chase & Simon, 1973; de Groot, 1965; Goldin, 1978). Allard et al. (1980) first modified this chess task for a sports context. Starkes (1987) then adapted this approach to field hockey where now there are 22 players on the field and the players have specific offensive and defensive roles. For her recall test, the game-structured scenes featured players in position around the striking circle and net area, whereas the nonstructured scenes depicted transition (turnover) situations. Participants viewed each scene for 8 seconds, and then attempted to recall each scene by reconstructing the player locations with magnets. The pattern of results for the 3 groups of differing field hockey expertise replicated that of Chase and Simon's (1973) (as shown in Figure 1). These data led to the conclusion that sport-skilled individuals were similar to chess masters in their enhanced ability to encode and retrieve meaningful units of domain-specific information and that this skill underpinned their decision-making advantage.

The recall (and recognition) paradigm has remained a popular technique in investigations into the effect of expertise on memory. In the recall paradigm, a stimulus is viewed (e.g., a video or still frame of a free-kick scenario in soccer) for a short period of time, around 3-8 s (depending on the complexity of the stimulus) and then players are asked to recall the configurations using pen and paper, or by placing pieces representing the different teams, onto a make-shift board of play. In the recognition paradigm, the dependent measure is the accuracy or speed (e.g., Williams

& Davids, 1995) with which participants can identify a previously viewed stimulus (e.g., Allard et al., 1980). Although recognition and recall both assess memory, they potentially reflect different encoding structures and retrieval processes. Hence, although we consider them together in this article, elsewhere they have been treated independently (see Roediger, 1990). Experts' superior recall and recognition of structured patterns has been demonstrated in American football (e.g., Garland & Barry, 1991), basketball (e.g., Abernethy, Baker, & Côté, 2005; Gorman, Abernethy, & Farrow, 2013a), field hockey (e.g., Abernethy et al., 2005; Starkes & Deakin, 1984), netball (e.g., Abernethy et al., 2005; Farrow, 2010), rugby (e.g., Farrow, McCrae, Gross, & Abernethy, 2010), soccer (e.g., Ward & Williams, 2003; Williams & Davids, 1995; Williams, Davids, Burwitz, & Williams, 1993; Williams, Hodges, North, & Barton, 2006), and volleyball (e.g., Borgeaud & Abernethy, 1987), as well as in dance (Starkes, Deakin, Lindley, & Crisp, 1987), figure skating (Deakin & Allard, 1991) and snooker (Abernethy, Neal, & Koning, 1994).

Recently, researchers have been motivated to uncover the essential information and processes underlying skilled recall and recognition (e.g., North, Williams, Hodges, Ward, & Ericsson, 2009; Williams et al., 2006; Williams, North, & Hope, 2012). For instance, Williams et al. (2006) examined the perceptual features important for pattern-recognition in soccer in a series of three experiments. They first confirmed the typical expert recognition findings; skilled defensive players were quicker than less-skilled players to identify structured (and non-structured) patterns of play in dynamic film sequences. To isolate the importance of each source of information, the film sequences were presented normally and as point-light displays in a second experiment. Converting film to point-light strips away the surface attributes of a visual scene, testing the importance of purely structural relations between features in making familiarity-based judgments. Though both groups were less accurate in the point-light condition, the skilled participants again demonstrated a recognition advantage. In a final experiment, a spatial occlusion paradigm was used to occlude the two central offensive players (assumed to provide the most salient information regarding an evolving pattern of play, Williams et al., 1993, 1994). As predicted, familiarity-based judgments were significantly degraded in the occluded condition, indicating that the removed offensive players provided essential relational information for pattern recognition.

This research served to highlight the role of relational information, and specifically that of key players in the encoding and recognition of game-structured patterns. In follow- up research, North et al. (2011) used verbal protocols to show that skilled soccer players viewed and encoded game structured patterns with more evaluative and predictive judgments than their less-skilled counterparts, suggesting greater representational complexity. Although this research supported the idea of a link between pattern recognition and predictive processes (see Abernethy et al., 2005; Williams & Davids, 1995), other data are not altogether clear with respect to the relationship between memory and decision-making. For example, it has been noted (Gorman, Abernethy, & Farrow, 2013b) that investigations that have used a multi-task approach have not shown recall performance to be strongly related to measures of prediction accuracy or speed (e.g., Farrow et al., 2010; Williams & Davids, 1995). Moreover, fixation behaviours were shown to differ across memory and anticipation tasks (North et al., 2009), as did retrospective verbal reports (North et al., 2011), suggesting that pattern recognition might not (or only partially) explain the expert advantage in decision-making. The point has been raised that pattern recall is not a typical task requirement in sport (Gorman, Abernethy, & Farrow, 2012; Ward, Williams, & Hancock, 2006) and may be just a consequence of experience playing, rather than an important skill. Considering that skilled individuals clearly have an enhanced capacity to encode and access domain-specific information, the potential functional purpose of such memory ability continues to be debated.

Anticipatory memory

The anticipatory nature of perception (and hence what is encoded during a visual inspection stage) has been well documented in the cognitive psychology literature, in terms of 'representational momentum' (see Intraub, 2002). Recall or recognition tests reveal a systematic bias of observers to encode objects as having moved forward in time (e.g., a falling object is recalled as being lower on its trajectory or a walking person farther along her path). Interestingly, these mental representations of projected events degrade performance through the 'false' recollection of as-of-yet unperceived (but anticipated) events (e.g., Freyd & Finke, 1984; Futterweit & Beilin, 1994).

The anticipatory nature of perception had previously been attributed to knowledge gained through experience (e.g., of objects' likely trajectories due to gravity, Hubbard, 1995), hence Didierjean and Marmèche (2005) examined whether anticipation processes also affect perception in a sporting context, as anticipation processes could be advantageous in such time-constrained environments. The results of two experiments supported this prediction. Expert basketball players demonstrated degraded performance on recognition tasks compared to novice basketball players and controls. The experts' recognition detriment pertained specifically to i) the differentiation of two configurations presented successively, when the second configuration depicted the next-likely state of the first (Experiment 1), and ii) the recognition of a configuration as novel when it represented the next-likely state of a previously encoded configuration (Experiment 2). These results showed a link between acquired, domain-specific expectations and the automatic projection and encoding of dynamic features of stimuli. Moreover, this study provided intriguing insight into the perceptual mechanisms that may be influencing – or even interfering with – experts' performance on traditional tests of memory for structured game information.

There have been recent concerted efforts to better understand the relationship between sport expertise and these prospective encoding processes (Gorman, Abernethy, & Farrow, 2011, 2012, 2013b). In particular, Gorman et al. (2012) studied how the accuracy of the participants' recall compared to the state of the target pattern at successive 40 ms increments, allowing quantification of the timeline of such prospective encoding. The experts anticipated the forward shifted locations of the depicted basketball players more so than the novices and on average 176 ms into the future. These anticipatory projections were also shown to be related to actual game decisions, whereby anticipatory recall was shown to be a better predictor of decision-making performance than traditional recall (Gorman et al., 2013b). The authors (2012, 2013b) suggest that this recent appreciation for the extent of the anticipatory nature of experts' perception, and its sensitivity to display-type (see Gorman et al., 2011), may mean that the relationship between experts' (traditional) recall and decision-making abilities may have been underestimated in the past (e.g., Farrow et al., 2010; Williams & Davids, 1995).

Generalizability of knowledge

The issue of pattern recall and recognition as fundamental skills underlying expertise in sports has also been researched with respect to transfer across sporting domains. Determining specificity versus generalizability of perceptual-cognitive skills has important theoretical and practical relevance for tactical learning and the types of memories that are formed through experience, as well as the training of athletes in similar sports.

Allard and Starkes (1991) first examined the transferability of pattern reading skills in skilled basketball and ice hockey players. The athletes demonstrated the best recall for patterns from their respective domains of expertise, but also appeared to perform relatively well on stimuli from the other sports (although no comparisons were made with novice control groups). There have since been a number of studies showing evidence of positive transfer between sports of perceptual-cognitive skills that previously appeared to be domain specific (for a review see Williams et al., 2011). In general, and perhaps not surprisingly, similarity across sports (in terms of structural, relational, and tactical elements) is most predictive of positive transfer (Smeeton, Ward, & Williams, 2004). Expert athletes have also been shown to outperform non-experts in the recall of defensive player positions in sports outside their domain of expertise, again suggesting some generalizability of perceptual-cognitive skill (Abernethy et al., 2005).

The transferability of acquired perceptual-cognitive abilities has also been investigated with respect to anticipatory recall (Gorman et al., 2011). However, unlike the between-sport recall advantages demonstrated above, soccer players' recognition accuracy for basketball scenarios did not reveal the same systematic temporal bias associated with the representational momentum effect (unlike expert basketball players). It is possible that soccer and basketball are not sufficiently similar to support the transfer of this nuanced pattern reading or that anticipatory processes are subject to domain specificity and can only be developed through playing the sport (Gorman et al., 2011).

The cognitive advantage in anticipatory predictions: Spatial and temporal occlusion

In addition to superior recall of game-structured information, Starkes (1987) also identified the decision-making component of action prediction as a significant predictor of sport-skill level. The task Starkes used to examine this perceptual-cognitive ability involved filming an elite field hockey player dribbling towards the goal and shooting to six areas. The videos were filmed from the perspective of a goaltender positioned in the centre of the net and the footage of the shots was edited to create stimuli that terminated either 150 ms before ball impact or 50 ms following ball impact (what is termed temporal occlusion). Shot prediction improved for all skill level groups when ball impact was viewed and again the National team players demonstrated superior prediction accuracy than either varsity or novice players, irrespective of viewing condition (see Figure 1, line graphs). When tasked with making predictions based only on advance visual cues (i.e., before ball impact), only the National group performed above chance.

While Starkes (1987) noted that there were few studies evaluating the use of advance visual cues in sport (for exceptions, see Bard & Fleury, 1981; Jones & Miles, 1978; Salmela & Fiorito, 1979), this is certainly not the case 25 years later. Considering the fast-paced and complex nature of interceptive sports, the ability to accurately and speedily anticipate others' actions (and the effects of these actions, e.g., a ball's trajectory) offers a clear competitive edge by enabling anticipatory rather than reactive movements. Much research has been devoted to identifying the information and processes underpinning this anticipatory skill over the last quarter century and many studies have now provided evidence that experts' ability to respond to action events, with seemingly time to spare, stems from their superior detection and interpretation of early movement information (for reviews see Abernethy, 1987; Hodges et al., 2007; Williams et al., 1999; Williams et al., 2011). Although a considerable body of research has been devoted towards the study of anticipatory cue usage through measures of visual search (i.e., eye movement recording), we focus our review below on studies that have adopted occlusion techniques (like those used by Starkes, 1987). Findings from visual search methods have generally complemented those obtained through measures of occlusion, providing specific information about where gaze is focused and hence what information is attended to before or during an anticipatory decision.

Temporal and spatial occlusion techniques have been useful in revealing the information guiding anticipatory decision processes (see Hodges et al., 2007; Williams et al., 2011; Yarrow, Brown, & Krakauer, 2009). The temporal occlusion paradigm enables researchers to manipulate the information available to viewers (generally by editing video footage or using occlusion goggles), in order to infer the critical time periods where essential cues about an unfolding event are conveyed. Similarly, spatial occlusion methods can be used to obscure some aspects of the visual scene to reveal the locational sources of the essential information guiding enhanced prediction accuracy (e.g., Abernethy, 1991; Abernethy & Zawi, 2007; Abernethy, Zawi, & Jackson, 2008). In some recent work, this technique has been used to restrict information to the athlete's fovea or periphery, based on a visual gaze related manipulation (Ryu, Abernethy, Mann, Poolton & Gorman, 2013; Schorer, Rienhoff, Fischer & Baker, 2013).

Using such occlusion techniques, experts' and novices' use of advance visual cues in action prediction has now been studied in a variety of sport contexts. The findings have consistently supported Starkes' (1987) reported expert advantage in anticipating the consequences of actions early in their unfolding (e.g., Hagemann, Schorer, Cañal-Bruland, Lotz, & Strauß, 2010). In a variety of sports, experts have been shown to be more accurate and quicker to interpret the predictive cues revealed in opponents' early movement behaviours and access to body kinematics typically provides this essential information for anticipation (e.g., Abernethy et al., 2008; Huys, Smeeton, Hodges, Beek, & Williams, 2008; Mann, Williams, Ward, & Janelle, 2007; Savelsbergh, van der Kamp, Williams, & Ward, 2005; Williams et al., 2011).

Considering the impressive ability of skilled athletes to accurately anticipate action events based on early movement cues, Rowe and colleagues (2009) investigated whether such cues could be effectively disguised to deceive athletes. Using a temporal occlusion paradigm, they studied expert and novice tennis players' anticipation of groundstrokes' landing locations. The experts were more accurate in predicting the fate of tennis strokes compared to novices but disguised actions effectively reduced prediction accuracy. However, the experts remained able to accurately anticipate shot direction based on the earliest preparatory movement cues (up until 40 ms before ball contact), before intentional disguising tactics appeared to have masked or distracted from the critical cues.

In summary, skilled athletes have learnt to read the game more effectively than their less skilled and less experienced counterparts. This results in an enhanced ability to see events unfolding in time, providing a time and accuracy related decisional advantage over lesser skilled peers. The ability of athletes to pick up and accurately interpret preparatory movement cues remains a marvel of the sporting elite. Starkes (1987) played a pivotal role in setting expertise research on its course by highlighting expert sportspeople's ability to use early visual cues in predicting action effects. Over the past quarter of a century, it was often theorized that experts' superior ability to anticipate domain-specific events in sports relied on their extensive memory stores and the efficiency with which they recognized and accessed such information (e.g., Ericsson, 2003; Starkes, 1987). More recently, there has been a noticeable, though small shift in perspective about processes underpinning these perceptual-cognitive skills. One such idea, based on the notion of common action and perception neural coding (Prinz, 1997), puts the emphasis on the motor system's involvement in anticipation accuracy rather than memory-related processing (Bishop et al., 2013; Yarrow et al., 2009). This is where we now turn our attention, where we focus on research that has emerged over the last decade, based primarily on neurophysiological effects, that have opened up new avenues of investigation and that have impacted our thinking as to mechanisms which underpin the cognitive advantage in sport.

Putting the "motor" back into the "cognitive": fMRI, TMS and secondary tasks

In this section we consider how a modern understanding of the relationship between perception and action impacts our thinking about the expert "cognitive" advantage. Current ideas about action simulation (e.g., Jeannerod, 2001) and computational models of motor control (e.g., Miall & Wolpert, 1996; Wolpert, Diedrichson, & Flanagan, 2011) offer contemporary means of considering the predictive nature of experts' perceptual-cognitive skills. With the development and greater availability of neuroimaging and neurophysiological measurement techniques, there is a growing body of empirical research documenting the neural mechanisms underpinning experts' superior perceptual-cognitive abilities, particularly as it relates to the involvement of the athlete's motor system.

The perception and execution of the same action have been shown to solicit the same neural structures in the brain and similarly trigger specific parieto-frontal neural networks within the so-called mirror neuron system (MNS, Buccino et al., 2001; Rizzolatti & Craighero, 2004) or action observation network (AON, Cross, Hamilton, & Grafton, 2006). Such cortical linkages have led to the theory that observed actions are mapped onto the viewer's own motor representations of the action, such that observers covertly simulate the actions they perceive (Jeannerod, 2001) and that this simulation contributes to anticipatory decisions. For relevance to the study of expertise, the extent of observers' neural activity during action observation has been shown to be modulated by their experience with a similar action (e.g., Buccino, Binkofski, & Riggio, 2004; Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005; Calvo-Merino, Grèzes, Glaser, Passingham, & Haggard, 2006; Cross, et al., 2006).

Action experiences change how we see

The research program of Calvo-Merino and colleagues (2005, 2006) provides an illustrative example of the modulating effects of motor capabilities on the perception of action. These authors used fMRI (functional Magnetic Resonance Imaging) to study the brain activity of expert ballet dancers (males and females) and capoeira martial artists during the observation of actions specific to each specialty or gender. Functional MRI maps brain activity by measuring the blood-oxygen-level-dependent (BOLD) signal. While this tool obviously constrains the tasks that can be examined (movement is prevented or significantly restricted inside the scanner), it has been useful in capturing expert-novice differences in response to a variety of sport-related stimuli. Increased neural activity was shown in the premotor and parietal brain cortices (areas implicated in the MNS, Grèzes & Decety, 2001; Rizzolatti, Fogassi, & Gallese, 2001) when movements were observed that were within the dancers' own specialized motor repertoires (e.g., ballet for ballerinas). Because expert male and female ballet dancers who train together also showed greater activation in motor regions of the cortex and cerebellum when watching videos of their own gender-specific movements, the authors concluded that when people observe they simulate actions in terms of their own motor representations of the actions and not in terms of shared visual experiences. This is important as it suggests that how we make sense of actions is influenced by our capabilities to perform those actions.

Anticipatory processes and the role of the motor system

The activation of motor-related areas of the brain during action observation has traditionally been thought to serve action understanding (Rizzolatti & Craighero, 2004). An extension of this proposal has been that the motor system's involvement in action perception contributes to the prediction of observed action effects, potentially via forward models (Eskenazi, Grosjean, Humphreys, & Knoblich, 2009; Gorman et al., 2013b; Wilson & Knoblich, 2005;

Yarrow et al., 2009). In computational models of motor control, forward models are the sensory consequences of self-generated action that are predicted based on an efference copy of the motor command (Miall & Wolpert, 1996). It has recently been proposed that when the MNS is activated via action observation, there is not only a simulation of the action in terms of the viewer's own motor representation, but as a corollary effect, a forward model is generated (Miall, 2003). The resultant sensory predictions have been proposed to be available to cognition (e.g., Frith, Blakemore, & Wolpert, 2000; Miall et al., 2006) and may be implicitly accessed when observing and anticipating unfolding actions (Eskenazi et al., 2009; Wilson & Knoblich, 2005).

As the first functional imaging study devoted to anticipatory skill in sport, Wright and Jackson (2007) attempted to identify the neural correlates separately implicated in 1) the viewing of sport-related motion and action, and 2) the anticipation and judgment of action outcomes. Novice tennis players were shown videos of serves, non-serve actions (ball bouncing), and static control sequences. Using temporal occlusion, the serve sequences were edited pre- or post-ball-racquet contact and predicted directions were made by pressing a button whilst in the fMRI scanner. Compared to the non-serve actions, the serve sequences demanding an anticipatory judgment elicited increased activity in MNS brain areas, specifically, regions in the parietal lobule (bilateral inferior parietal lobule, right superior parietal lobule) and in the right frontal cortex (dorsal and ventral regions of the inferior frontal gyrus). This pattern of activation was separate from the responses in areas of the brain associated with the general viewing of motion and body actions (middle temporal visual area, superior temporal sulcus), suggesting that action prediction relies on brain areas implicated in actual action execution to help predict the outcomes of actions.

In a subsequent, cross-sectional comparison across skill level, Wright et al. (2010) again used temporal occlusion to manipulate the kinematic information available to inform expert, intermediate, and novice badminton players' predictions of an opposing player's shot direction. In all groups, early occlusion of the sequence led to increased activity in premotor cortical regions and the medial frontal cortex. Experts showed increased activation in the dorsolateral premotor, ventrolateral frontal, and medial frontal cortices (areas implicated in the observation, understanding, and preparation of action, Wright et al., 2010), particularly when relying solely on early movement cues to make predictions. Again, this research suggests that low-level movement preparation aids the experts' cognitive advantage in making anticipatory decisions about shot outcomes.

Fronto-parietal components of the action observation network were similarly activated during expert and novice basketball players' prediction of the fate of a basketball free throw shot (i.e., in or out, Abreu et al., 2012). Experts showed increased activation in the extrastriate body area (EBA), which the authors suggest may be an effect of the athletes' greater reliance on and interpretation of body kinematics in predicting the outcomes of others' actions (e.g., Abernethy & Zawi, 2007; Aglioti, Cesari, Romani, & Urgesi, 2008). Experts showed increased activation in the bilateral inferior frontal gyrus and right insular cortex when watching errors.

TMS (transcranial magnetic stimulation) is another technique that has been used to show that the prediction of action outcomes in sports involves the motor system. The use of TMS in investigating motor simulation follows the rationale that the perception of bodily motion (and skilled motion in particular) changes neural excitability in the primary motor cortex. By applying TMS to primary motor cortex during the viewing of actions, enhanced corticospinal activity can be captured using electromyography (EMG) of the motor evoked potentials (MEPs – measures of corticospinal excitability) in the effector(s) involved in the viewed action (typically hand, arm or foot muscles).

In a temporal occlusion paradigm, whereby a basketball free throw shooter was shown making successful or unsuccessful shots, Aglioti and colleagues (2008) applied TMS during viewing of these actions in order to stimulate hand, wrist and arm muscles involved in shooting a basketball. Expert players and expert watchers (i.e., coaches/sports journalists) showed enhanced corticospinal excitability when observing basketball shots, in comparison to novices. However, only expert players showed increased hand muscle MEPs for shots that missed the basket. Given that the athletes were also shown to be most accurate in anticipating the outcome of basketball free throw shots (compared to expert watchers and novices) and that this advantage was most pronounced for early clips before the ball had left the hand, these data suggest that expert athletes' anticipation skill is related to their ability to simulate (at a low-level) what they are seeing. These refined motor simulation mechanisms then provide the athlete insight into the effects of actions specific to their own motor capabilities.

This group of researchers (i.e., Tomeo, Cesari, Aglioti, & Urgesi, 2013) has also used TMS to show how interactions between the perceptual and motor systems affect expert athletes' sensitivity to deceptive movements and depend on the position-specific experiences of the athletes. Expert soccer kickers were more likely to be fooled by fake actions (where an observed kicker's body kinematics and the ball trajectory did not match up) than novices and expert goalkeepers. Moreover, through measurement of MEPs in response to TMS, "fooling" actions elicited similar lower-limb motor facilitation as to that seen for real actions in the expert kickers only. Differences between goalkeepers and expert kickers suggests that anticipatory decisions might be a result of different mechanisms in players who have primarily motor experience with the action (i.e., expert kickers), in comparison to goalkeepers who have acquired more visual experience predicting penalty kick direction.

There have, however, been criticisms of these methods and conclusions (Mann, Dicks, Cañal-Bruland, & van der Kamp, 2013). Some of this criticism is based on the stimuli used to show "deceptive" actions (where there is no intentional modification of body kinematics by the actor, which would be better representative of "fooling"). As well, Mann et al. generally caution about the ability to make generalizations about perceptual-motor expertise based on neurophysiological findings, not least because the measurement techniques place extreme limitations on the tasks and responses that can be captured. This might change in time, but for now insights from this technique need to be weighed against results from other studies and methods. A technique that is gaining in popularity is tDCS (transcranial direct current stimulation). Like rTMS, it is possible to stimulate a specific area of the brain with effects lasting after the stimulation, such that it is possible to study that brain area's role in certain tasks or actions without the need to control movement. tDCS works by passing a low voltage current through an area of interest, essentially changing neural excitability in an area of the brain. It is a relatively inexpensive method in comparison to TMS, although there is a need to know where to apply the stimulation, which might require whole brain fMRI before application of tDCS. To date, tDCS has not been used to enhance sports performance, yet see Banissy and Muggleton (2013) for a consideration of its potential value in sports training.

In our laboratory we have considered how to test ideas concerning the role of the motor system in making predictive decisions without using neurophysiological techniques. In a dart-throwing training study performed with novice participants, we were able to show post-test improvements on a perceptual decision task (i.e., judging outcomes of throws based on temporally occluded videos) after motor-training only (Mulligan & Hodges, 2013). We removed vision of the throwing action and dart flight during practice with visual occlusion goggles and compared performance to groups who had full vision or only visual experience watching. Importantly, only groups who physically practiced the darts task improved on their anticipatory decisions and these groups did not differ from each other. A second method we have used to determine motor system involvement in these anticipatory decisions is via use of secondary tasks. Here we have shown that motor-tasks (incongruent to the observed action) interfere with anticipatory decisions of skilled darts players (Mulligan, Lohse, & Hodges, in review). Importantly, only motor tasks that were different to the action being watched interfered, and this interference was only seen for experts and not for cognitive secondary tasks matched in terms of attention demands.

In summary, these studies serve to highlight the role of the motor system in generating perceptions and predictions about what might happen (and ultimately what to do) in sport-specific scenarios. There are of course limits to some of these approaches with respect to the types of tasks that can be studied and the general difficulty in assessing performance when people are realistically responding. Moreover, just because a particular area of the brain is activated during these perceptual-cognitive tasks, this still does not allow us to distinguish what participants are actually doing when they make decisions, that is, whether they access perceptual or motor images, whether they generate actions and then suppress them, whether they rely on some generative action processes in addition to recognition of past events. These techniques and ideas should, however, prompt reflection as to what it means to argue for a perceptual-cognitive account of expertise, when there is considerable evidence that these seemingly perceptual-cognitive decisions are bound in the action capabilities of the observer and require motor system involvement, at least at a cortical level, to function effectively.

Past issues, current debates and the future of the cognitive advantage in sports

In considering a current view of the cognitive advantage in sports and the implications of Starkes' work on the field we highlight a few particularly telling quotes from the 1987 paper that help to provide a general framework for our final section and discussion of the studies and issues raised in this review. These quotes show how many of the same issues still remain a quarter of a century later as well as how the field has advanced and Starkes' prescience in anticipating future developments in sport expertise.

"In motor skills, the issue remains how much of one's knowledge structure evolves from doing – physically performing in the context – and how much evolves from watching and problem-solving" (*Starkes, 1987, p. 158*).

Neurophysiological measurement has changed the way we think about perceptual processes and what is gained from watching. The identification of shared perceptual and action neural networks and their physical experience-induced malleability has added to our understanding of the processes underpinning perceptual-cognitive expertise in sport. Although there is still debate about how experts' predictions are enabled with respect to the calling up of domain-specific perceptual memories or through simulation-type processes, there is at least a greater appreciation for the dualistic relationship between action and perception. Although we have known for a long time that perceptions need to be tied to actions for memory or anticipatory advantages to be evident, we now know more about how perceptual codes or skills develop merely as a result of moving. It will be exciting to see how the field develops with respect to advances in technologies and our understanding of the embodiment of perceptions and cognitions. It is becoming increasing clear that knowledge gained from watching and problem solving is different in nature to that gained from actually doing and hence we anticipate that more passive methods of perceptual training, while potentially serving to enhance some aspects of decision-making, will always need to be considered in tandem with perceptual training methods aimed at training the motor or visual-motor system.

"One's operational definition of expert versus novice and where the two groups fall along the much broader range of performance in that skill, becomes critical" (*Starkes, 1987, p. 158*).

We would extend Starkes' (1987) call for design vigilance to encompass not only the characteristics of the participant groups, but also those of the actors featured in experimental stimuli. Similar suggestions for greater task representativeness have been made by others (e.g., Araujo & Davids, this issue) in order for us to better understand differences in performance between various skill groups. There is behavioural evidence showing that the closer the match between an actor and observer's motor skills, the better the viewer's recognition of an action (Loula, Prasad, Harber, & Shiffrar, 2005) and action-prediction (Knoblich & Flach, 2001; Knoblich, Seigerschmidt, Flach, & Prinz, 2002). Thus, in the sport expertise literature, it is important to consider how the similarity between the actor and observer groups' motor capabilities factors into their perceptual-cognitive performance and the inferences that can be made. To our knowledge, there have been no attempts to compare perception or anticipation differences when a novice sports player has provided the visual stimuli in addition to the typical skilled model. Moreover, with the exception of one study (Jackson, van der Kamp, & Abernethy, 2008), there have been no other attempts to examine differences in perception or anticipation of self-generated (versus other-generated) sporting actions. Such manipulations to the model featured in experimental stimuli merit consideration. The inclusion of self- and novice-action stimuli can provide insight into the sensitivity of action simulation systems for the anticipation of action outcomes and potentially alert as to how expert athletes' perception may be worse when action consequences are less predictable (e.g., when associated with novices' less consistent motor performance), in comparison to that of more novice or intermediate athletes.

In our laboratory we have shown that although predictions are more accurate when watching self- versus other-generated darts clips among motor experts, for both types of stimuli, decision processes were both affected by motoric secondary tasks (Mulligan et al., in review). There was some evidence that the effects were stronger for self- versus other- stimuli, yet the novices did not show interference from a secondary motor task for any of the stimuli. Given the lack of any motor experience for the novice group it is not too surprising that predictions were not affected by task type. However, it is possible that beginner or intermediately-skilled performers may prove better able to anticipate the outcomes of novice action (i.e., performances closer to their own) than a more expert group. This would of course raise some issues about coaching and refereeing and what type of person (in terms of past or current motor skills or experiences) would make the best perceptual-cognitive decisions (for an illustration of such interactions based on motor experience, see Dosseville, Laborde & Raab, 2011; Pizzera, 2012). It is possible, of course, that after a certain refinement of an action, further fine-tuning ceases to significantly influence perceptual-cognitive processes, or at least those captured by current behavioural measures. For instance, Abreu et al. (2012) found no differences between skilled basketball players' ability to anticipate shot outcomes, despite their experience ranging from 468-6552 hours of practice (yet see Bezzola, Mérillat, Gaser, & Jäncke, 2011). More research is required to assess these potential skill-based interactions and the degree of match between skill/experiences and perceptual-cognitive performance. As Bishop et al. (2013) suggest, neural activation during perceptual-cognitive activities is likely not simply contingent upon the number, but also upon the quality, of practice hours accrued.

“As a cognitive skill [field hockey] appears more like games such as chess and basketball than volleyball” (*Starkes, 1987, p. 156*).

Starkes was at the forefront of the shift in the conceptualization of expert athletes, from one of gifted individuals with generally superior hardware traits, to one of experienced individuals with acquired, domain-specific software skills. Despite this apparent domain-specificity, Starkes reflected that similar skills would be relevant in a variety of contexts. More recently, researchers have probed the specificity versus generality of perceptual-cognitive abilities, in attempts to infer the extent to which they are specialized to the domain in which they were acquired.

Some positive transfer of pattern reading ability has been shown between sports with similar structural, relational and tactical demands (Smeeton et al., 2004). The phenomenon of prospective pattern encoding, however, appears to be a defining attribute of motor-visual experts with specific experiences in their sport (Gorman et al., 2011). Soccer players did not demonstrate the typical effects of anticipatory recall processes when presented with basketball configurations, potentially because such anticipatory processes uniquely develop in conjunction with domain-specific motor experience. Future investigation into sports where some transfer of traditional pattern recognition skill has been found (e.g., soccer and field hockey, Smeeton et al., 2004) using a paradigm designed to capture representational momentum may help to provide more insight into the necessity of direct motor experience in the development and generality of anticipatory recall processes.

Sport-based neurophysiological data appear to favour the specificity of such expertise-driven, perceptual-cognitive attributes. For example, expert athletes experienced greater motor resonance when imaging (Fourkas, Bonavolontà, Avenanti, & Aglioti, 2008) and anticipating the effects (Aglioti et al., 2008) of actions within their domain of expertise (e.g., basketball rather than soccer). Expert dancers similarly exhibited selectively enhanced neural activity not only when viewing domain-specific versus aesthetically similar movements (Calvo-Merino et al., 2005), but also when viewing gender-specific versus non-gender-specific movements within the relevant domain of expertise (Calvo-Merino et al., 2006). There is evidence that the specificity of expert anticipatory skill extends to the level of positional roles within a sport (Williams, Ward, Ward, & Smeeton, 2008; see also Raab & Farrow, this issue). This specificity is proposed to be an effect of position-specific cognitive representations accrued with visual-motor expertise (Williams et al., 2008, 2011). Finally, there has been a significant body of research published of late on the left-handed advantage in sport, which is thought to be due to the development of perceptual skills or the lack of visual familiarity with left-handers (e.g., Loffing, Hagemann, & Strauß, 2012; Loffing, Schorer, Hagemann, & Baker, 2012). Considerations as to how hand-dominance might favourably influence the expert advantage in perception and cognition in interactive sports highlights how general abilities change specific visual-motor experiences within a domain. Whether the left-handed advantage is related to difficulties simulating (perhaps it's hard to simulate kicking a ball with your left foot when you are primarily a right-footed player) in addition to merely a lack of experience seeing and responding to left-footed or handed people, is also a question for future research.

There has been recent evidence that some executive functions predict success in sport and that athletes can be distinguished based on general cognitive traits or skills. For example, in a study of soccer players, skilled (High Division) soccer players achieved higher scores on measures of creativity, response inhibition, and cognitive flexibility than less skilled (Lower Division) soccer players, who in turn outperformed a standardized norm group (Vestberg, Gustafson, Maurex, Ingvar, & Predrag, 2012). In a prospective component of this study, these authors showed that test results significantly predicted success in soccer (i.e., the number of goals and assists achieved) two seasons later.

Such a relation between general cognitive abilities and sport success calls for contemplation as we reflect back on the quarter century year old question of the nature of sport expertise. If general executive functions reflect innate hardware abilities, what does this mean for the notion of the cognitive advantage and the hierarchy of acquired software skills over inherited traits? Of course, it is possible that these skills were acquired as a result of significant experience playing soccer, although traditionally these types of skills would not have been considered domain-specific software skills. There is also research in video-gaming that serves to question the dichotomization of hardware and software abilities. Rather than there being a simple distinction between innate and acquired attributes, Green and Bavelier raise the possibility that "hardware" traits such as attention skills and information processing can be trained within a specific domain, with improvements generalizing to untrained tasks (e.g., Dye, Green, & Bavelier, 2009; Green & Bavelier, 2003, 2007). Although video-gaming does not place the same motor demands on the performer as most sports-skills, there is still a strong link between perception and motor demands, such that it is worth following this research in the future, especially with respect to the transfer of skills.

Conclusions

We have provided a review and evaluation of the nature of the cognitive advantage in sport as conceptualized by Starkes (1987) in light of some of the early and more current research dealing with perceptual-motor skill in sport. We have been somewhat selective in the areas we have chosen to review, mostly as a result of our desire to consider the cognitive advantage as it relates to the main tasks studied by Starkes in 1987 (pattern recognition, recall and prediction accuracy). We had also wished to consider what it means to talk about a cognitive advantage in sports in the context of neurophysiological research and newer perspectives concerning the role of the motor system and action experiences in expert perception and decision-making. The interested reader is directed to other articles in this special issue on other research related to expertise in sport. Most notably, our consideration of studies relating to visual search among skilled sportspeople and perceptual training techniques are limited (for a recent review see Causer, Janelle, Vickers, & Williams, 2012; Williams, et al., 2011), as is our discussion of the sports decision-making literature more generally (for a review see Bar-Eli, Plessner, & Raab, 2011).

In 1987, Starkes aptly captured skilled sports people's superior recall and anticipatory skills. That these perceptual-cognitive abilities distinguish skilled over less skilled individuals in a domain-specific context is uncontested to this day. While the basic conclusions have not changed, they have been extended by the concerted efforts of expertise researchers over the last quarter of a century to identify the processes underpinning these abilities. The ability to predict the outcomes of unfolding actions and patterns of play has traditionally been attributed to the development of sophisticated memory encoding and retrieval processes. However, a growing body of neurophysiological research, commensurate with contemporary theories of motor simulation and computational models of motor control, unveils another layer of the processes contributing to expert perceptual-cognitive abilities. It is now thought that observed actions are mapped onto the viewers' own motor 'representations' of the action, and it is on the basis of this simulated motor activity that predictive processes are generated and extrapolated in order to anticipate the effects of others' action. There is growing evidence that motor capabilities modulate these perceptual-motor processes, with important implications for how the nature of the expert 'cognitive' advantage in sport is conceptualized, how sport skill is operationally defined, and how such abilities are understood to be generalizable or specific to the domain of expertise.

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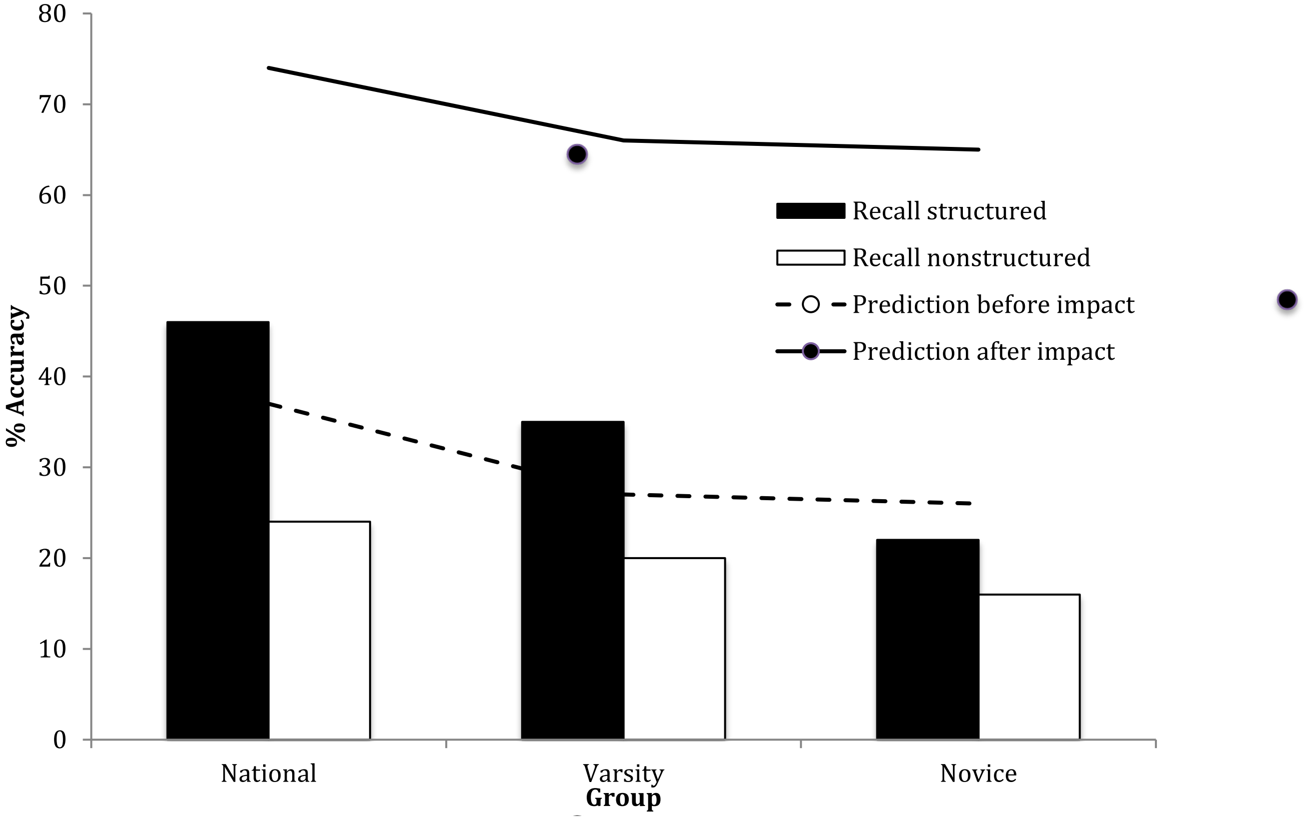
Figure Heading

Figure 1. Adapted from Starkes (1987). Mean % accuracy for the recall of structured and nonstructured game information (shown as bars) and mean % accuracy in predicting shot location before and after ball impact (shown as lines) for National, Varsity and Novice level field hockey players.


80
70
60
50
40
30
20
10
0
% Accuracy
Recall structured
Recall nonstructured
Prediction before impact
Prediction after impact
National
Varsity
Novice
Group