Perceptual-Cognitive Expertise in Sport and its Acquisition: Implications for Applied Cognitive Psychology

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Summary: We review contemporary research on perceptual-cognitive expertise in sport and consider implications for those working in the field of applied cognitive psychology. We identify the important perceptual-cognitive skills that facilitate anticipation in sport and illustrate how these skills interact in a dynamic manner during performance. We also highlight our current understanding of how these skills are acquired and consider the extent to which the underlying processes are specific to a particular domain and role within that domain. Next, we briefly review recent attempts to facilitate the acquisition of perceptual-cognitive expertise using simulation training coupled with instruction and feedback on task performance. Finally, we discuss how research on elite athletes can help inform applied cognitive psychologists who are interested in capturing and enhancing perceptual-cognitive expertise across various domains. Copyright © 2010 John Wiley & Sons, Ltd.

In recent years there has been considerable interest in exploring the nature of expert performance across domains (e.g., Ericsson, Hoffman, Charness, & Feltovich, 2006; Ericsson & Williams, 2007). For example, scientists with an interest in sport have analysed the perceptual-cognitive skills underpinning anticipation in this domain and identified how these processes are acquired through prolonged engagement in practice (for reviews, see Hodges, Huys, & Starkes, 2007; Williams & Ford, 2008; Williams & Ward, 2007). The scientific study of skill acquisition has a long history in experimental psychology, dating back to the early studies of Bryan and Harter (1899). In more recent times, Poulton (1957) was the first to systematically discriminate between different types of anticipation judgements using experimental methods common to this discipline. The scientific study of anticipation as a field of inquiry in its own right in sport psychology has a much shorter history, emerging primarily in 1970s (for a historical overview, see Williams, Davids, & Williams, 1999). The majority of sport psychologists work in multi-disciplinary departments where research in traditional discipline areas, such as physiology, psychology, and biomechanics, often develops somewhat independently of academicendeavour within the main disciplines themselves. The empirical findings that have been reported on anticipation in the field of sport psychology could therefore contribute to the generation of new knowledge on this topic in the parent discipline area, and particularly in applied cognitive psychology.

Sport offers a relatively unique environment where the limits of human achievement are challenged continually. This environment provides a fertile context to identify the essential skills and attributes for performance as well as the underlying processes that discriminate individuals with varying levels of performance. Such knowledge provides a basis for determining what types of practice activities are likely to lead to the acquisition of skill across domains and, potentially, why some individuals improve at different rates to others or achieve much higher performance levels (Ericsson, 2006). This information may subsequently be used to evaluate the applicability of general theories of expertise and skill acquisition, to design appropriate interventions for performance enhancement, and to identify factors that contribute to enhancing the processes of talent search and talent development across different fields of human endeavour (Ericsson & Ward, 2007; Williams & Ericsson, 2005; Williams, Ericsson, Ward, & Eccles, 2008).

In this review paper, we synthesise recent research on perceptual-cognitive expertise in sport and consider potential implications for those working within the field of applied cognitive psychology. We focus exclusively on research that has attempted to identify the perceptual and cognitive processes underpinning anticipation. The ability to anticipate is crucial to performance in sport as well as in many other domains such as military combat, law enforcement, and everyday tasks such as driving a car. These situations require performers to determine the intentions of others and to formulate an appropriate response often under severe temporal constraint. In fast ball sports such as tennis, the time taken for the ball to travel from one opponent to the other is often shorter than the combined sum of an athlete’s reaction time and movement time, implying the need to initiate a response ahead of the opponent actually striking the ball (Williams et al., 1999). Since most sports, and in particular racket sports and team ball games, require athletes to process information in a time-constrained environment, it is necessary for performers to adapt to the unique constraints of the task by acquiring knowledge structures and cognitive processes that allow them to anticipate. The ability to anticipate allows athletes additional time to formulate and execute an
appropria}e response. We document attempts to ascertain how anticipation and the processes underlying it are acquired in sport. Moreover, we outline efforts to facilitate the acquisition of such processes using simulation-based training. Our aim is to illustrate using specific examples how research on perceptual-cognitive expertise in sport can help identify some of the general mechanisms and adaptations that facilitate anticipation in other domains, thereby contributing more broadly to the field of applied cognitive psychology.

IDENTIFYING THE PROCESSES UNDERPINNING ANTICIPATION

Over recent decades, there have been concerted attempts to identify the specific skills and processes involved when making anticipation judgements in sport settings. Some important perceptual-cognitive skills have been identified that relate to how athletes recognise and use their expectations of future events to guide their decisions and actions. In this section, we briefly review this literature and consider how the importance of these perceptual-cognitive skills may vary as a function of the task constraints.

Recognising and using task-relevant, postural information provided by others

A substantial body of research highlights the ability of expert athletes to anticipate the outcome of a situation accurately based on the postural movements of their opponent/s (for detailed reviews, see Hodges et al., 2007; Williams & Ward, 2007). In fast ball sports, this ability enables athletes to prepare and execute their own response in order to counter the intentions of opponents. The temporal and spatial occlusion paradigms have been used to evaluate individual differences in the ability to recognise and use postural cues (Müller, Abernethy, & Farrow, 2006; Williams & Davids, 1998). An opponent is filmed from a first-person perspective performing a given action (e.g. tennis serve) and these images are then projected to participants life-size on a large screen. Participants are required to anticipate their opponent’s action or the outcome of the situation either by responding verbally, using pen-and-paper or physically (e.g. by performing an action in response to the stimuli presented). In the temporal occlusion paradigm, the film sequences are occluded at varying time periods relative to a critical event (e.g. ball-racket contact during the tennis serve). In the spatial occlusion paradigm, information is removed by occluding part of the scene while still presenting the remainder of the stimulus (e.g. the opponent’s arm or racket is occluded). The relative decrement in performance on the occluded conditions relative to a control condition involving the occlusion of an irrelevant information source provides an indication of the relative importance of each source of information.

Alternative approaches have been used that permit the specific postural cues on which this type of anticipation is based to be identified. For instance, researchers have used liquid crystal glasses to occlude vision in the actual performance setting (e.g. Müller & Abernethy, 2006; Starkes, Edwards, Dissanayale, & Dunn, 1995) or a head-mounted, corneal reflection system to record visual search behaviours either in situ or when viewing film-based simulations of the performance context. A large amount of research has been conducted examining the visual search behaviours of athletes during performance. In many sport tasks, expert athletes have been shown to use qualitatively different visual behaviours when extracting information from the performance environment compared to less-skilled athletes. It is beyond the scope of this paper to summarise this literature, but interested readers are directed elsewhere to a number of detailed reviews (Williams et al., 1999; Williams & Ward, 2007; Williams, Janelle, & Davids, 2004).

Several researchers have proposed that the effective pick up of relative motion is an essential component of anticipation in fast ball sports (e.g. Abernethy, Gill, Parks, & Packer, 2001; Ward, Williams, & Bennett, 2002). The argument is that performers anticipate the actions of an opponent based on their perception of the relative motion between specific bodily features, rather than via the extraction of information from an isolated area/cue or more superficial features. In order to address this issue, researchers have extended prior research (e.g. Cutting & Proffitt, 1982) by examining skill-based differences in the ability to anticipate the outcome of an opponent’s actions when presented as biological motion or point-light displays (e.g. Ward et al., 2002). To create the point light stimuli, the motions of real players performing an action are captured using optoelectronic motion analysis system or digitised from filmed images. Skilled performers are able to maintain an advantage over novices in anticipating the outcome based on their more accurate interpretation of the motion information presented in the display.

Williams and colleagues (e.g. Cañal-Bruland & Williams, 2010; Huys, Smeerston, Hodges, Beek, & Williams, 2008; Williams, Huys, Cañal-Bruland, & Hagemann, 2009) have extended this approach by manipulating the dynamical information presented to participants. In addition to presenting tennis shots in point light form, these authors manipulated the dynamical properties of the action by occluding or neutralizing the kinematics at a selected body region, or by interchanging them with those from strokes played to the opposite side of the court. The primary aim of this research was to examine the importance of subtle changes in dynamical information when attempting to anticipate different types of actions.

While information from the end-effector (i.e. arm and racket) is often sufficient to accurately anticipate shot direction in tennis, skilled tennis players are able to extract helpful information from other areas of the body such as the shoulders, trunk and legs (Huys et al., 2009; Cañal-Bruland & Williams, 2010). It appears that skilled performers rely on a more ‘global’ rather than ‘local’ perceptual strategy when perceiving the actions of others. Skilled performers are able to extract relevant information from several areas simultaneously, implying a degree of redundancy or flexibility in the perceptual strategy employed. A more global perceptual strategy may make experts less prone to attempts by opponents to deceive or disguise their intentions (Jackson, Warren, & Abernethy, 2006; Williams et al., 2009).
RECOGNISING FAMILIARITY AND STRUCTURE IN THE PATTERNS EMPLOYED BY OTHERS

The ability to recognise familiarity and structure within the performance environment was originally tested in the domain of chess using the classical recall and recognition paradigms (e.g. Chase & Simon, 1973; Goldin, 1978). Allard, Graham, and Paarsalu (1980) were the first to use these paradigms in sport. In separate experiments, they demonstrated that skilled basketball players were more accurate than less-skilled players in both recalling and recognising information presented in structured sequences of play that represented actual match-play scenarios, whereas, in contrast, this skill superiority disappeared when sequences were presented as random configurations of players. Skilled athletes, like Grandmasters in chess, encode task-specific information into meaningful configurations that are accessed during recognition and recall of structured patterns of play. These findings were subsequently replicated in other sports and games such as American football (Garland & Barry, 1991), snooker (Abernethy, Neal, & Konning, 1994), and soccer (Williams & Davids, 1995).

More recently, there have been attempts to better identify the processes underpinning the recognition of structured sequences, as well as the extent to which this particular skill is actually related to anticipation. Williams, Hodges, North, and Barton (2006) examined the relative importance of superficial display features (e.g. colour of players’ uniforms, environmental conditions, condition of playing surface) and structured relational information (e.g. positions and/or movements of players) when recognising sequences of play. Skilled and less-skilled soccer players completed a recognition test where sequences of play were presented under both film and point-light conditions. In the point-light condition, the positions and movements of players were highlighted as coloured dots against a black background with the field of play represented as white lines. Superficial features such as the colour of players’ uniforms, postural cues, or the condition of the playing surface and other environmental effects were removed. Although skilled players had lower accuracy scores in the point-light condition compared to the film condition, the decrement was less marked compared to less-skilled players and the skill main effect was maintained across viewing conditions. In line with research on analogical problem solving (e.g., Gentner & Markman, 1998), skilled performers are able to recognise patterns of play based upon structural relations and the higher-order predicates they convey (e.g. tactical and strategic significance of these relations between players), whereas less-skilled players depend almost exclusively on more superficial structural features.

In follow up studies, efforts were made to ascertain whether some structural relations (e.g. spatial relationship between two key task-relevant features) convey more information than others (North, Williams, Ward, Hodges, & Ericsson, 2009; Williams & North, 2009; Williams et al., 2006). In one study a spatial occlusion technique was employed to remove certain relational features from the action sequences during the recognition phase, whereas in other studies visual search data and retrospective verbal reports were gathered as players attempted to make familiarity-based recognition judgements. When attempting to identify sequences of play the ability to pick up relative motion information between a few key features either in isolation or in conjunction with other features is crucial.

Several researchers have proposed that the ability to recognise patterns of play is central to anticipation in team sports (e.g. Abernethy, Baker, & Côté, 2005; Williams & Davids, 1995), whereas others have proposed that these are incidental memory adaptations that are acquired as a consequence of engaging in practice on representative domain-relevant tasks (e.g. Ericsson & Lehmann, 1996). North et al. (2009) analysed the visual search behaviours employed during anticipation and recognition, respectively to address this issue. Skilled participants showed no differences in fixation transitions between key features across the two tasks, indicating a broad, relation-based perceptual strategy. However, in contrast, there was evidence that the two tasks require somewhat different processing strategies. When instructed to anticipate rather than recognise film clips, participants fixated on more locations, showed an increase in the number of fixations, recorded shorter fixation durations and spent different periods of time fixating various display areas.

Williams and North (2009) reported similar conclusions based on retrospective verbal report protocols. When asked to anticipate rather than recognise sequences of play participants verbalised more stimuli, actions and cognitions, albeit on both tasks the skilled players made more relevant evaluations than less-skilled players. Although both anticipation and recognition tasks stimulate complex retrieval structures, the processes involved in activating these structures differ somewhat. While recognition may be involved in anticipation to some degree, the latter skill is more complex invoking different retrieval structures (cf. Cañal-Bruland & Williams, 2010).

The findings from this programme of work lend support to Dittrich’s (1999) Interactive Encoding Model. Dittrich (1999) proposed that individuals combine both low- and high-level cognitive processes when making recognition-based judgements. Participants initially extract low-level relational information and temporal relationships between features, before engaging in high-level processing where the information extracted is judged in the context of some stored memory structure. One interpretation is that the stimulus presentation is matched with an internal semantic concept or template (Didierjean & Marmèche, 2005; Gobet & Simon, 1996). The proposal is that skilled players develop an extensive knowledge base of encountered scenes and potential scene formations, which are stored as semantic concepts or templates. Less-skilled players have fewer templates and so processing is unrefined and based primarily on the recognition of distinctive surface features. An alternative interpretation is provided by Ericsson and Kintsch’s (1995) Long-Term Working Memory theory, which proposes that experts develop complex task-specific encoding skills and associated retrieval structures in long-term memory. These retrieval structures allow experts to index and store information at encoding, such that features or collections of features can permit superior representation.
of current scenarios and facilitate both recognition and anticipation of events (Ericsson, Patel, & Kintsch, 2000). These complex information structures in long-term memory are accessible through cues held in short-term memory. The proposal is that Long-Term Working Memory helps performers develop an encoding for a situation, which, in turn, facilitates monitoring, the formulation of planning actions, and continual evaluation of the present situation and planned actions.

Using probabilities and expectations in a situation

It has been suggested that expert athletes are able to anticipate how a scenario will unfold based on their understanding of the probabilities that a future event will occur in a given situation. An anticipated outcome is pursued if expectations are matched up with the available sensory evidence. The human brain is presumed to employ some form of Bayesian strategy based on the statistical distribution of likely event probabilities and the level of uncertainty in the sensory feedback evolving from the emerging display (Kording & Wolpert, 2004).

The role of event probabilities in sport was initially examined using laboratory-based choice reaction time paradigms (e.g. Alain & Proteau, 1980). However, there have been recent attempts to develop more representative methods using sport-specific stimuli (e.g. Crognier & Féry, 2005; Ward & Williams, 2003). Ward and Williams (2003) showed a series of 10 second duration filmed sequences of match action to elite and sub-elite soccer players. In each trial at the end of the sequence the final frame of action was frozen on screen. Participants were required to highlight on a paper copy of the frozen frame the options available to the player in possession of the ball and then rank order those options in order of threat to the defence. The elite players were better than the sub-elite group at highlighting the key options and were more accurate at ranking those options in order of threat, as determined by an independent panel of expert coaches. In contrast, sub-elite players were less efficient in their selection and ranking of key options.

McRobert, Williams, Ward, and Eccles (submitted) used a novel paradigm to illustrate how cricket batsmen develop accurate expectations that enable them to predict the type of delivery that they are likely to face. The batsmen were required to play a simulated stroke in response to life-size filmed representations of bowlers’ deliveries. In one condition, the batsmen viewed a total of 36 random deliveries from ten different bowlers, whereas in a second condition batsmen were presented with an entire over (i.e. six consecutive deliveries) from each of six bowlers who had delivered only one ball each in the first condition. The performance of the batsmen on the final delivery from each six-ball over in the second condition was compared with that on the same delivery when presented as an independent trial in the first condition.

The cricket batsmen improved their anticipation accuracy in the second condition which contained additional contextual information compared to the random viewing condition. Progressive changes in the visual search behaviours and think-aloud verbal reports collected from participants were apparent across the two conditions. When more contextual information was presented, batsmen altered their gaze behaviours to spend more time fixating on central (i.e. head-shoulder region) rather than peripheral (i.e. ball-hand) areas. They articulated more higher-order statements involving prediction and planning compared to lower-order statements such as monitoring and evaluation. The observed differences between the random and contextual conditions suggest that the skilled batsmen were able to develop better expectations of the type of delivery that a bowler is likely to perform and use this information to guide and refine their search for task-relevant information. The influence of contextual, game-related information on successful anticipation has also been reported in baseball (McPhershon and MacMahon, 2008) and tennis (Crognier & Féry, 2005).

How does the relative importance of these perceptual-cognitive skills vary as function of task constraints in sport?

Thus far, few researchers have examined how the different perceptual-cognitive skills interact with each other in a dynamic and evolving manner to facilitate anticipation in the competitive setting (Williams & Ward, 2007). A reductionist approach has typically been employed with researchers focusing their efforts on developing paradigms that isolate each perceptual-cognitive skill for systematic investigation under controlled and reproducible conditions. However, Roca, Ford, and Williams (2009) used a novel approach to examine how different perceptual-cognitive skills interact during performance in a dynamic, simulated task-environment. Skilled and less-skilled players were presented with offensive sequences of play filmed from the perspective of a central defender in soccer. The sequences of play either started with the ball being located in the opposition half of the pitch (i.e. far situation) or in the participant’s defensive half (i.e. near situation). The dynamic sequences, which lasted for 5–6 seconds each, were presented on a large screen and were occluded at a key moment in the action. Participants were required to anticipate the actions of their opponent and choose the most appropriate strategic decision to make in response to the situation. Verbal report protocols were gathered immediately after each sequence and then collated using an inductive, task-analysis procedure.

As expected, skilled defensive players demonstrated superior anticipation and decision-making when compared with their less-skilled counterparts. Verbal reports highlighted the continuous and dynamic interaction between the different perceptual-cognitive skills. These findings are highlighted in Figure 1. In the far task, participants made more statements that referred to the postural orientation of teammates and opponents, followed by expectations about event outcomes, and finally relational information between players, whereas, in the near task, players verbalised more thought processes that were related to the identification of relational information (i.e. pattern recognition) and situational probabilities when compared to the far task. Overall, the skilled players made more inferences to situational probabilities and pattern recognition than their less-skilled counterparts.
A suggestion is that several additional constraints influence how important different perceptual-cognitive skills are at any given moment when making anticipation judgements (Williams, 2009). For example, when anxious, athletes have been shown to reduce search rate and narrow their focus of attention, potentially reducing the capacity to use peripheral vision and influencing the relative importance of different sources of information (Williams & Elliott, 1999). Similar changes in visual search have been shown when athletes are fatigued (Vickers & Williams, 2007). A key issue is that the importance of these perceptual-cognitive skills is likely to be highly dynamic, varying considerably depending on a range of factors or constraints. Unfortunately, few researchers have attempted to identify the different constraints (e.g., emotion) and how they influence the importance of these perceptual-cognitive skills.

In similar vein, these findings have potentially significant implications for the manner in which we try to capture and enhance perceptual-cognitive skills across domains. If the different perceptual-cognitive skills are observed to interact in a dynamic manner during performance, then the value of a reductionist approach to try and capture (or train) one component or skill in isolation may be questioned. It is beyond the scope of this paper to consider how each of the different methods presented in the paper may be combined to provide a more complete picture of perceptual-cognitive expertise in a particular task or domain, but interested readers are directed elsewhere for this information (e.g., Williams & Ericsson, 2005).

**HOW ARE THE PROCESSES UNDERLYING ANTICIPATION ACQUIRED?**

In this section, we review recent attempts to identify how perceptual-cognitive expertise is acquired. In particular, we consider how engagement in the correct type and amount of practice activities facilitates the acquisition of perceptual-cognitive skills. Moreover, we examine the extent to which perceptual-cognitive skills are specific to a particular sport and role within that sport or whether there is evidence to support the notion that these skills are transferrable and generalise across different contexts.

**Influence of practice**

Since the seminal work on deliberate practice by Ericsson, Krampe, and Tesch-Römer (1993), several researchers have examined the practice history profiles of elite athletes. These authors argued that continued improvements are dependent on deliberate efforts to improve important aspects of performance rather than the repetitive execution of routine work. Practice should be challenging in relation to its level of difficulty, informative due to the availability of feedback, and repetitive with an opportunity to detect and correct errors. A combination of semi-structured interviews, questionnaires, and training logs have been used to collect retrospective data on the type and amount of practice accumulated over the athlete’s career span (e.g., Ward, Hodges, Starkes, & Williams, 2007).

Most recently, researchers have used the deliberate practice approach to identify specific practice activities that contribute towards the development of anticipation in sport. Baker, Côté, and Abernethy (2003a; see also 2003b) examined the role of sport-specific practice in the development of perceptual-cognitive expertise in the sports of field-hockey, netball, and basketball. The practice history profiles of international level athletes deemed by national team coaches to be experts in terms of their anticipation and decision-making skills were contrasted with those of a control group of intermediate level performers deemed to be non-experts on these particular dimensions of performance. The experts had accumulated more hours in sport-specific practice compared to non-experts. Moreover, the experts spent more time in activities that they, and the non-experts, deemed to be the most helpful in developing perceptual-cognitive skills (e.g., video training, organised team practice, individual instruction with a coach and competition).
particular, time in competition was reported as the most helpful activity in developing perceptual-cognitive skills. In similar vein, Berry, Abernethy, and Côté (2008) examined the developmental histories of players in the Australian Football League who were either expert or less-expert in relation to their perceptual-cognitive skills. Although there were no differences between these two groups of players in the hours of practice accumulated in Australian Football, the expert group reported spending more time in structured, invasion-type activities that had similar demands to Australian Football. This study suggests that some perceptual-cognitive skills transfer across sports and that participation in sports that share some characteristics may facilitate the development of anticipation skill over and beyond the amount of sport-specific practice accumulated.

In a recent study, contradictory findings have been reported using a sample of elite level soccer players (Williams, Ford, Bell-Walker, & Ward, submitted). In this study, elite level participants were stratified into ‘high performing’ and ‘low performing’ based on their performance on established tests of perceptual-cognitive skill in soccer. No significant differences were reported in the total number of hours accumulated in match-play, coach-led practice activity in soccer, the number of other sports in which they engaged or the total hours accumulated in other sports. However, the most discriminating variable was the number of hours spent in soccer-specific, non coach-led play activity. The participants who were ‘high performing’ as far as their perceptual-cognitive skills were concerned had accumulated more hours over their career in play activity in soccer (i.e. street soccer) when compared with their ‘low performing’ counterparts.

Several advantages may arise as a result of extended engagement in sport-specific, play activity. Participants are allowed the freedom to experiment with different skills, techniques, and tactics within their sport. Such conditions create the opportunity to innovate, improvise, and respond strategically, re-creating those conditions that are important at the elite level in many sports. The increased variety and greater opportunities for anticipation and decision-making that likely arise may help facilitate the acquisition of flexible and adaptive perceptual-cognitive skills. One should note however, that only when these activities are supported by engagement in substantial practice does expertise emerge. In the absence of practice, engagement in play, deliberate or otherwise does not lead to skilled performance (Ford, Williams, Hodges, & Ward, 2009; Ward et al., 2007). Further research is needed to better understand the roles of nonsport-specific and sport-specific play in the acquisition of perceptual-cognitive expertise.

**Specificity vs. generality**

Another question related to notions of specificity and generality is to what extent is the development of perceptual-cognitive expertise specific to a particular sport or even the position or role within that sport. Smeeton, Ward, and Williams (2004) employed the recognition paradigm to address this issue in the sports of soccer, hockey, and volleyball. Soccer and hockey were predicted to share common structural (e.g. 11 players on each side on similar size pitch), relational (e.g. players’ positions and movements), and tactical elements (e.g. principles of play such as width in attack and depth in defence) and consequently, some transfer of perceptual-cognitive skills was predicted when compared to a relatively dissimilar sport such as volleyball. Participants completed separate recognition tests in each of the three sports. As predicted, no significant differences in performance were evident between the skilled soccer and hockey players on the structured soccer and hockey sequences respectively, with both groups reporting superior performance on these sequences compared to the skilled volleyball players. In contrast, the skilled volleyball players demonstrated much lower accuracy scores when responding to the soccer and hockey sequences compared to their performance on the volleyball trials. The identification of playing sequences in soccer and hockey may be mediated by common underlying principles (e.g. Gentner, 1983), implying that there is some transfer of perceptual-cognitive expertise across sports. Similarly, Abernethy et al. (2005) reported some selective transfer of recognition skills in groups of expert netball, basketball, and field-hockey players.

Although findings illustrate the possibility that perceptual-cognitive expertise may transfer across sports, at no point did athletes perform better on a related sport when compared with their corresponding performance on the primary or main sport. One should therefore not infer that practice in a related sport (e.g. field hockey) may be better for developing perceptual-cognitive expertise than engaging in the primary sport (e.g. soccer). Moreover, there have been no attempts to identify the mechanisms underpinning transfer effects. It would be helpful to identify using process-tracing measures (e.g. eye movement recording, verbal protocol analysis) the specific processes employed by experts as they attempt to identify sequences of play in similar and dissimilar sports. Nonetheless, findings are encouraging and suggest that experts are able to integrate novel stimuli into existing encoding and retrieval structures to facilitate both recognition and transfer (Ericsson & Kintsch, 1995).

Williams, Ward, Smeeton, and Ward (2008) extended this work to examine whether the level of specificity extends to a particular positional role within a sport. A group of expert offensive soccer players, a group of similarly skilled defensive players, a group of novice offensive players and a group of similarly novice defensive players completed a film-based anticipation test. The expert defenders were significantly more accurate in their judgements than their equally expert offensive counterparts, with both of these groups performing better than novice defensive and offensive players. Since the primary task for defenders is to anticipate the actions of attacking players, they are likely to develop more refined, position-specific cognitive representations to facilitate anticipation skill compared to offensive players. Offense players are, by definition, in possession of the ball and so, other skills (e.g. decision-making) are likely to take precedence over anticipation of the actions of an opposing player. In sum, expert defenders develop cognitive representations that are position- as well as sport-specific (Didierjean & Marmèche, 2005; Ericsson & Kintsch, 1995).
HOW CAN THE ACQUISITION OF THESE SKILLS BE FACILITATED VIA RELEVANT TRAINING INTERVENTIONS?

In this section, we consider whether the acquisition of perceptual-cognitive expertise may be facilitated through the use of systematic training interventions. This issue has attracted increasing interest over recent years, albeit there remains a need for more systematic and cohesive programmes of research to fully examine the practical utility of such interventions (for detailed reviews, see Ward, Williams, & Hancock, 2006; Ward, Farrow, Harris, Williams, Eccles, & Ericsson, 2008; Ward, Suss, & Basevitch, 2009; Williams & Ward, 2003).

The vast majority of researchers have attempted to improve the ability of athletes to pick up advance visual cues from an opponent’s postural orientation. Unfortunately, relatively few, if any, researchers have attempted to enhance pattern recognition or situational assessment (for an exception, see Williams, Heron, Ward, & Smeeton, 2005). The most frequently used approach has been to simulate the performance environment using film (e.g. return of serve in tennis) and then to provide instruction as to the important sources of information, coupled with practice, and feedback in relation to performance on the task (e.g. Smeeton, Williams, Hodges, & Ward, 2005; Williams, Ward, & Chapman, 2003; Williams, Ward, Knowles, & Smeeton, 2002). Alternative approaches have involved the use of field-based interventions either in isolation or in conjunction with film-based training (e.g. Farrow & Abernethy, 2002) and virtual reality simulations of the performance setting (e.g. Walls, Bertrand, Gale, & Saunders, 1998). Overall, this research work illustrates the practical utility of these types of interventions in facilitating the acquisition of specific perceptual-cognitive skills.

Another body of work has focused on the relative effectiveness of different approaches to instruction. Williams et al. (2002) compared the effectiveness of guided discovery with a traditional explicit instruction approach when developing the ability of novice performers to anticipate the direction of forehand and backhand drive shots in tennis. After completing a pre-test in the laboratory and field respectively, participants completed 45 minutes of laboratory based training, 45 minutes of on-court instruction, followed by a post-test in the laboratory and field setting. In the group of novice tennis players who received explicit instruction, the key postural cues were highlighted during training. The group who received guided discovery instructions were merely directed towards potentially informative areas of the display, such as the trunk or hips, encouraging them to discover meaningful relationships between various postural cues and shot outcome. In the laboratory, players were required to respond in an interceptive manner to filmed images involving tennis forehand and backhand shots presented on a large screen, whereas on-court the players’ responded to a live feed from another tennis player.

The two experimental groups significantly reduced their response times on the laboratory and on-court post-test relative to matched placebo (watched tennis instructional videos) and control (completed pre- and post-tests only) groups. There were no significant differences in response accuracy across groups or test sessions. No significant differences were observed between the two training groups; both groups were significantly faster on the post-test when responding and this improvement transferred to the field setting. The guided discovery approach was at least as effective as more traditional, prescriptive approaches to instruction.

In a follow up study, Smeeton et al. (2005) examined the relative effectiveness of explicit instruction, guided discovery, and discovery learning methods in improving anticipation in 12-year old, intermediate level tennis players. A longer acquisition period was employed involving 4 × 20-minute sessions over a 4-week period, as well as a delayed retention test involving an anxiety manipulation. Film-based training was used in which participants viewed the shots of opponents occluded at ball-racket contact. Instruction was provided after each clip and then participants viewed the same shot without occlusion allowing them to see the eventual outcome. All three training groups significantly improved performance pre- to post-training when compared to a control group, highlighting the benefits of film-based simulation training. Participants in the explicit and guided discovery groups improved performance during acquisition more rapidly than the discovery learning group. However, the explicit group showed a significant decrement in performance when tested under anxiety provoking conditions compared to the guided-discovery and discovery learning groups. The findings are presented in Figure 2. While explicit instruction may result in more rapid improvements in performance during acquisition, less prescriptive instructional approaches lead to more robust learning effects and greater resilience under pressure.

![Figure 2. The decision times reported for the four participant groups on (a) laboratory- and (b) on-court based pre- and post-tests (data from Smeeton et al., 2005)](data:image/png;base64,iVBORw0KGgoAAAANSUhEUgAAAEEAAAD2CAYAAAAQHlqYAAAABGdBTUEAALGPC/xhBQAAAAFElmiscAwAADQAAAQgAAAAwFJRU5JTQl5TQAAAADUlEQVR42mG4dGwBwD...
Numerous questions have yet to be answered adequately such as: What is the relative effectiveness of the different types of training media (e.g. video vs. on-court vs. virtual reality)? Can each perceptual-cognitive skill be trained in isolation or do they need to be trained together in the manner they are used in actual performance? Would this type of training be most effective with a particular age or skill group? How should perceptual-cognitive training programmes be structured for optimum learning? There remains considerable scope for those interested in exploring innovative methods to facilitate the acquisition of perceptual-cognitive expertise in sport, as well as in other domains such as medicine, the military, and law enforcement (for reviews, see Ward et al., 2006, 2008, 2009).

IMPLICATIONS FOR APPLIED COGNITIVE PSYCHOLOGY

In this final section, we consider how research on perceptual-cognitive expertise in sport can impact on those interested in applied cognitive psychology. In particular, we consider how research on elite athletes can influence the methods and measures used to evaluate performance across domains. Also, we examine how the typical focus in sports science on translational research that impacts performance can influence research in applied cognitive psychology.

Novel methods and measures

Psychologists undertaking research with elite athletes have been particularly innovative in attempting to develop methods and measures that enable performance to be captured objectively and reliably in laboratory and field situations. In the laboratory, film-based simulations, virtual reality, and physical simulators have all been used successfully to capture performance (e.g. Ward et al., 2006; Williams & Ericsson, 2005). The use of movement sensitive pressure mats, infra-red motion detectors, optoelectronic motion analysis systems, accelerometers, and high-speed video analyses have provided accurate and sensitive response measures. In the field setting, high-speed film, liquid crystal occlusion glasses, digital coding technology, satellite, and camera-based player and ball tracking technology have all been employed to help evaluate aspects of sporting performance in situ (Carling, Williams, & Reilly, 2008). Moreover, there have been attempts to record process-tracing (e.g. visual search, verbal reports) as well as outcome measures simultaneously during performance (e.g. McRobert, Williams, Ward, & Eccles, 2009; Vaeyens, Lenoir, Williams, Mazyn, & Philosophers, 2007).

Most psychologists interested in expertise in sport are employed in sports science or kinesiology departments, providing a fertile environment for multi-disciplinary research between biomechanics, exercise physiology, and behavioural neuroscience. In biomechanics, high-speed film, electromyography, force transducers, in-shoe recording pressure devices, optoelectronic cameras, electrogoniometers, and force platforms are standard items of equipment. Such devices provide accurate and sensitive tools to examine the kinetics (i.e. forces) and kinematics (i.e. motion characteristics) of behaviour under controlled conditions. In exercise physiology, physical workload, environmental conditions, and stress can all be manipulated to examine their effects on perceptual-cognitive processes (e.g. Vickers & Williams, 2007). Finally, an increasing number of scientists are now employing neuroscience methods to provide a window on the perceptual-cognitive processes employed by expert athletes (e.g. Wagg, Williams, Vogt, & Higuchi, 2009; Wright, Bishop, Jackson, & Abernethy, 2010; Yarrow, Brown, & Krakauer, 2009).

An advantage of working in a relatively new field is that scientists are keen to embrace new methods, measures, and manipulations from a broad range of discipline areas in a concerted effort to ascertain how best to capture expert performance. Only when the superior performance of experts can be systematically reproduced under controlled and realistic conditions that mimic those evident in the actual performance setting can we begin to examine experimentally the mechanisms mediating the acquisition of expertise. The field of Applied Cognitive Psychology (if one includes related fields such as Human Factors, Engineering Psychology, Cognitive Engineering, Cognitive Technology, Cognitive Ergonomics, Human-Computer Interaction, and Applied Cognitive Science) has generally embraced the integration of novel technologies, both as a central research focus in and of itself (i.e. human-technological interactions) and, specifically, as a means to develop better research methodologies for studying expertise and expert performance in complex, technological environments. However, those holding a stricter definition of Applied Cognitive Psychology (that excludes these broader disciplines) have preferred to use contrived tasks and adapt laboratory-based methods to study applied problems rather than embrace technological innovations and less traditional methods. The current review, hopefully, demonstrates that simulation-based technology and other measurement systems can be used to create representative task environments in which expert performance can be reliably measured, without having to forego experimental control in order to increase ecological validity, representativeness, and salience (Hoffman & Defenbacher, 1992). Accordingly, applied cognitive psychology researchers might benefit from better embracing new technology and forging close collaborations with other discipline areas in order to more appropriately capture key elements of the domain and to remain at the forefront of these technological and methodological developments (Ericsson & Ward, 2007).

A focus on application: Translational research on expert performance

Scientists interested in expertise in sport have a strong tendency to focus on the relevance or applicability of their work to performance enhancement within the domain (e.g. Farrow, Baker, & MacMahon, 2008; Williams & Hodges, 2004; Williams & Ford, 2009). This natural tendency to engage in translational research that examines how scientific findings in the laboratory can be converted into effective interventions that impact on society should be encouraged and embraced wholeheartedly by other disciplines. The need for a more interactive exchange between researchers in the
laboratory and the field has gained increasing prominence in recent years (e.g., Ericsson & Williams, 2007). The process should be viewed as bidirectional, embracing the need to isolate aspects of successful interventions for systematic analyses under controlled experimental settings with the more traditional pathway from theoretically motivated laboratory studies to the field of application (Vernig, 2007; see also Woods, 1998).

Although attempts to bridge the gap between science and practice are already evident in bidirectional traditionally applied fields such as medicine and the health sciences, the importance of translational research should be embraced in all fields of scientific discovery. While funding agencies have typically asked applicants to highlight how proposed work addresses issues relevant to societal phenomena, there is increasing awareness of the need to move towards a more complete translation from information derived in the laboratory to the development of interventions that impact on society in a meaningful way (Ericsson & Ward, 2007; Ericsson & Williams, 2007; Simonton, 2003). This dialogue between research fields that promote epistemological utility and those that promote ecological utility (Hoffman & Deffenbacher, 1993), whether laboratory- or field-based, is essential for the development of evidence-based practices and superior professionals irrespective of domain. The coverage of research in this review paper would suggest that this process is well underway in the area of perceptual-cognitive expertise in sport.

In conclusion, we have provided an overview of research on anticipation in sport. A number of perceptual-cognitive skills work together in an integrated and dynamic manner to facilitate anticipation. These skills include the ability to pick up postural cues from an opponent, to identify structure or patterns within evolving sequences of play, and to accurately predict events based on their likelihood of occurring. These perceptual-cognitive skills are acquired through prolonged engagement in certain types of practice activities which result in specific adaptations mediated by the development of more refined and elaborate encoding and retrieval processes in memory. Preliminary findings suggest that there may be some transfer of perceptual-cognitive expertise across sports, albeit equally compelling is the notion that perceptual-cognitive skills are both sport and role specific. An increasing body of empirical research exists to suggest that the acquisition of perceptual-cognitive expertise may be enhanced through simulation-based training and through engagement in specific types of practice activities. Finally, implications of research on perceptual-cognitive expertise in sport for applied cognitive psychologists were considered.

REFERENCES


