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Introduction

The goal of this chapter is to present what is currently known about expert performance in sport. Research on expert performance in sport is a relatively recent area of inquiry covering only the last 30 years. Our view of its evolution is that there have been 3 overlapping phases in its development. During the 1970's and 1980's much of sport research employed recipient paradigms popular within experimental and cognitive psychology. Typical research of this time involved testing skilled and less-skilled or novice groups of athletes on sport specific tests of recall and recognition, temporal and spatial occlusion of visual information, and anticipation. Again, following general trends in psychology verbal protocal analyses of expert athletes were also published. Toward the end of the 1980's, developments in the recording and analyses of eye movements and kinematic data made it feasible to examine the eye movements of expert performers in contrast with less skilled individuals to determine what athletes focused on and how their eye movement patterns differed from less skilled athletes (for reviews see Starkes, Helsen & Jack, 2000; Williams & Hodges, 2004). The focus until the 1990's was largely perceptual-cognitive and aimed at establishing where differences existed between experts and novices within a particular sport domain. One of the issues that plagued much of this early research was establishing who was an "expert" and what was an acceptable metric of expert performance.

Ericsson and Smith's (1991) publication was instrumental to the second phase in sport research in that it outlined 3 stages in examining expert performance: first, delineating aspects of expert vs. novice performance in a specific domain; next, designing laboratory tasks that tap those measurable and reproducible aspects of expert performance and determine the underlying mechanisms responsible; and third, the development of a more generalized theory of expert performance. The goal now shifted from merely demonstrating expert-novice differences in a sport to developing laboratory tasks to elucidate the underlying mechanisms that afford consistent expert performance. As a result many studies over the past 15 years have made concerted efforts to examine the underlying mechanisms of expert performance in sport (See Starkes & Ericsson, 2003).

During this time Ericsson, Krampe and Tesch- Römer's (1993) model of deliberate practice also had significant impact on research in sport. Over the past 12 years research on this model has been conducted in soccer, wrestling, figure skating, triathlon, swimming, netball, volleyball and basketball (see Ward, Hodges, & Starkes, 2004). The deliberate practice model has been examined more often in sport than in any other domain to date.

The last few years have seen the emergence of different paradigms in what we see as the third and most recent phase in the development of research on expert performance in sport. Ecological psychology, dynamical systems and principal component analyses show interesting and novel results and are expected to play a more important role in future in our understanding of performance in sport (see Beek, Jacobs, Daffertshofer, & Huys, 2003; Huys, Daffertshofer, & Beek, 2004). At present there are only a few studies available on expert performance using these techniques. A major advantage of these paradigms is that they view perception and action as inextricably linked. This focus on movement as integral to performance is particularly appealing when one considers the level of movement skill inherent in world class sport performances.

Since the vast majority of existing research on this topic has been approached from a cognitive perspective that is the major focus of this chapter. Given the volume of cognitive research available on sport, the complexity of issues that have arisen, and the relatively short length of this chapter, our focus is to provide the reader with a brief overview of key issues and methods, as well as the major findings to date from a largely cognitive perspective.

The chapter is comprised of three main sections. In the first section, we introduce some unique issues that need to be considered when studying *sport* performance. The second section begins with a review of the historical roots of this area of research. In this second section, we first present the literature from a cognitive perspective, outlining the different research paradigms such as anticipation, the identification of perceptual features, recall and recognition, and decision-making. This is followed by a discussion of perceptual training as one means of improving performance. A competing theoretical perspective is then presented with discussion of ecological psychology and the idea that perception is 'educated'. The second section concludes with presentation of research on the influence of practice for sport expertise. In the final section of the chapter we discuss and evaluate the first meta-analysis of sport expertise research (Thomas, Gallagher & Lowry, 2003).

<u>Unique features of sport as a performance area</u>

Sport performance demands proficiency in tasks that involve movement with severe time constraints, and very often interaction with moving objects and opponents. While sports differ from what are commonly perceived as more cognitive tasks such as bridge, and chess playing, there are also tremendous differences *among* sports. Witness the difference between a relatively slow-paced introspective game of golf and the fast-paced interceptive games of tennis or basketball. As well, the unique combination of requisite cognitive skill with movement skills may result in mismatches in the development of each area. For example a young second baseman in baseball may understand the necessity to throw a ball to cut off a runner to home, but simply not be able to make that throw (Nevett & French, 1997). Finally, sport demands may differ depending on the role occupied by the performer as a player within a team, as a coach, or referee. For example, anticipating a player’s next offensive move is an important skill for a player or a referee (who needs to get ahead of the play), but not very relevant to a coach. Adjusting a team’s defensive strategy to deal with an opponent’s offensive structure is most relevant to a coach and player but inconsequential for a referee. One’s role in a sport is an important factor in determining the nature of skills that are critical. Likewise, one’s role is often quite different in individual sports vs. team sports. A football quarterback’s role and skills are quite different from those required of a linebacker.

Movement. The most salient feature of sport is the central role that movement plays. Athletes perform movements that vary from the seemingly simple, such as running, to the extremely complex – such as a gymnastics bar routine. Moreover, many sports involve the coordination of movements between two or more athletes. This is the case in sports such as pairs figure skating, rowing, or team synchronized swimming. Elsewhere, a distinction has been made between *interactive* sports (basketball, soccer, ice hockey) that involve many interdependencies between players, and *coactive* sports (bowling, archery, golf) that are performed independently (Cratty, 1983). This distinction has been useful in determining the skill requirements and relative demands for communication that a sport presents. Some sports (rowing, swimming, track relays) however, demonstrate characteristics and thus demands of both (see Eccles & Tenenbaum, in press for a review).

Time constraints. A critically important aspect that must be taken into consideration in sport is the limit on performance imposed by inherent time constraints in a game. For open sports (see Poulton, 1957 for a discussion of open versus closed sports), often characterized as those in which athletes react to the movements of their opponents, the timing of action is critical to success. Not only do performers have to deal with deciding *when* to perform a skill, the actual *execution* of the skill also has time constraints. For example, an ice hockey player may be presented with an opportunity to score when the opposing team's goalie is temporarily out of position. However, the shooter only has a time window of milliseconds in which to select, prepare, and execute a successful shot. Once the hockey player has decided to take a shot, the action must follow instantaneously. The window of opportunity is wasted if the goalie is given the chance to prevent the shot, or the shooter's intentions are telegraphed to the goalie by a slow windup. One reason for this pressure is the systemic lag time intervening between an event and a decision to move (i.e., reaction time) and between this decision and its actual initiation and completion (i.e., movement time). This pressure on movement choice (response selection) and completion (response execution) is illustrated most clearly in fast ball sports. In sports such as tennis, squash and baseball there is little or no time for a lag between movement choice and movement. In these sports, movement decisions must often be made based on early and incomplete information. For example, a baseball batter facing a 90mph fast-ball must decide whether to swing or not before the ball has even left the pitcher's hand. In this scenario, there are constraints imposed by movement choice, movement timing, and coincidence anticipation.

Different abilities develop at different rates. The combination of movement demands, time constraints and interaction with moving objects creates a need for both perceptual-cognitive and perceptual-motor skill for high-level sport performance (e.g., Starkes, Cullen & MacMahon, 2004). Thus, an athlete's performance level depends on the development of these two interactive types of skills. This creates yet another unique situation in sport where a performer may have mismatches in the level of development of these two forms of skill. For example, an athlete may know *what* to do, but not *how* to do it (French, Nevett, Spurgeon, Graham, Rink & McPherson, 1996; Nevett & French, 1997). This mismatch can result in either poor motor performance, or a movement choice that is less than optimal.

Differing roles. While it has not received a great deal of attention within the literature, another unique aspect to sport is that individuals play different roles. Within a sport, the requisite skills for a soccer goalkeeper are quite different from those of a forward. Within track and field, a female sprinter has a very different skill set than a female javelin thrower. Likewise, one's role within a sport may differ such that the requisite skills for a coach (e.g., Côté et al., 1995; Salmela & Moraes, 2003) differ from those of judges and referees (e.g., Ste-Marie, 2003). While a coach, athlete, and referee may operate within the same "sub-domain" or specific sport, there is evidence that the different task demands result in different skills and abilities (e.g., Allard, Deakin, Parker & Rodgers, 1993; Williams & Davids, 1995). To date however, the vast majority of the literature on expert performance in sport has dealt exclusively with athletes. A second issue creates problems for any empirical test of role. Most often, coaches and referees begin their career as athletes and thus have subsumed various roles throughout their athletic career.

Teams are more than a group of individuals. One aspect of team sports often ignored is that teams require successful processes of coordination and communication well beyond the skills required of individuals. Yet it is only recently that teams have been examined from the same social cognition approach that is common in industrial and organizational psychology. Eccles and Tenenbaum (in press) suggest that because team operations are performed by multiple or cooperating individuals these must be coordinated or integrated to achieve the best performance. Thus the team must not only perform the task itself, but coordinate members' actions toward the task. In order to do so all team members must have shared mental models about the necessary behaviors of the team and its members, and have shared expectations. In addition there must be a general team knowledge of operations that is shared by everyone, yet more specific individual knowledge appropriate to certain positions or roles is also necessary. While sport performance shares many similarities with industrial and military applications, to date the research on teams as process units is minimal.

Historical roots of the expertise approach in sports

One of the earliest studies of perceptual-motor expertise was that of Bryan and Harter (1897; 1899), in their now classic investigation of telegraphic skill (see Lee & Swinnen, 1993). The sending and receiving of messages via Morse code required correct production in the timing of signals and correct translation of incoming messages. Bryan and Harter observed that experienced operators were more accurate and consistent in their productions than the less experienced and showed qualitatively different strategies in receiving messages, delaying the copying of the message until some idea of content and meaning was conveyed. In comparison, the novice operators copied messages letter by letter.

Although Bryan and Harter did not specifically use the term 'chunking' to discuss their findings (see Miller, 1956), they were one of the first to experimentally show that skill-based differences were a result of the (re)organisation of small units of information, such as letters, into larger units, such as words and phrases. Perceptual chunking ideas have been at the forefront of explanations for expert-novice differences in purely cognitive domains (Chase & Simon, 1973; Ericsson & Polson, 1988) and also in sport (see, Starkes, Helsen & Jack, 2000; Starkes, Cullen & MacMahon, 2004; Tenenbaum & Bar-Eli, 1993; Williams, Davids & Williams, 1999).

The ability to quickly and efficiently process domain-specific information has since been shown to be one of the defining features of expertise in sport and hence explanations for skill-based differences in motor skills have been heavily grounded in cognitively-based theories of information processing activities (e.g., Fitts, 1965; Fitts & Posner, 1963; Schnieder & Shiffrin, 1977). Accordingly, the performer was seen as an intelligent receiver and translator of information resulting in various degrees of effective output or behavior. Time delays between a stimulus and a response; that is the RT (reaction time) interval, provided a critical index of processing efficiency and skill. Three somewhat independent processing activities have been proposed to mediate the reception of information and motor behavior: stimulus identification, response selection, and response programming (see Schmidt & Lee, 1999;), such that skilled performance has been interpreted at a specific level in terms of the type of processing activities engaged in at these various stages (e.g., Tenenbaum, 2003). At a more general level, differences in the processing activities of skilled and less-skilled performers in sport have been described on the basis of the verbally-mediated, cognitive and conscious-awareness nature of the performance (e.g., Adams, 1971; Anderson, 1983; Fitts & Posner, 1963). These experimental findings, protocols, and theoretical approaches have been the foundation of much of the laboratory-based experiments designed to examine the mechanisms responsible for the expert advantage in sport, including the nature of the knowledge structures (e.g., McPherson, 1993) and control processes (e.g., Beilock & Carr, 2002) underpinning expert performance. Some of the classic findings in this area will be presented next.

The cognitive nature of the expert advantage in sport

Anticipation and Decision-making. The exploitation of advance information through highly developed internal stores and effective organization of the motor system has been proposed to underlie fast behavioral responses in the environment. This results in what Abernethy describes as the time paradox wherein skilled performers operating under extreme time constraints appear to have 'all the time in the world' (Abernethy, 1991). Recognition of familiar scenarios and the chunking of perceptual information into meaningful wholes and patterns speeds up processes related to stimulus identification. Processing activities associated with response selection can be reduced via knowledge and experience of previous stimulus-response situations and hence situational probabilities (e.g., Alain & Proteau, 1979, 1980; Nougier, Ripoll & Stein, 1989; Ward & Williams, 2004). Finally, as motor learning improves, processes associated with motor programming become more efficient and the degree of programming necessary for motor skill execution is reduced. In this way the whole action is merely parameterized or tuned based on prior experiences rather than constructed in terms of its individual components (see Schmidt, 1975; Schmidt & Lee, 1999).

In tennis (Goulet, Bard & Fleury, 1989; Fleury, Goulet & Bard, 1986) and baseball (Paull & Glencross, 1997) the expert advantage has been evidenced through superior decisions and RTs in response to unfolding game scenarios. In cricket, squash and badminton, Abernethy and Russell (1984) and Abernethy (1988, 1990) showed that skilled performers made more accurate decisions concerning stroke selection in cricket and shot direction in badminton and squash. Professional goalkeepers in soccer were better able and faster at predicting shot-location

(Savelsburgh, Williams, van der Kamp & Ward, 2002). Even as task complexity increases, as with the 11 versus 11 scenario in soccer, Williams et al. (1994) showed that skilled soccer players were faster and more accurate at verbalizing the future destination of the ball (see also Helsen & Pauwels, 1992).

Identifying perceptual 'structure' through occlusion studies and visual search. There have been a variety of methods employed in sport to examine the specific nature of the information underlying the expert advantage in both speed and accuracy (faster and more accurate decisions/responses). One of the most common methods is that of occlusion as first operationalized by Abernethy and Russell (1984). They determined that information could be occluded either temporally (by specific periods of time in relation to ball contact for example), or spatially (via the removal of specific features or events within a display) (see Abernethy, 1988; Abernethy & Russell, 1984, 1987; Williams, et al., 1999; Williams, Ward & Smeeton, 2004;). With respect to temporal occlusion studies, it has been shown that the expert advantage is most clearly observed when a structured game clip, in tennis (e.g., Goulet et al., 1989) or in goal-keeping (e.g., Savelsburgh et al., 2002) for example, is edited prior to ball-racquet or ball-foot contact. In these situations, experts are able to use advance visual cues to predict shot-type and direction, whereas the less skilful players do not have this perceptual skill at their disposal. In this way, temporal occlusion studies help to elucidate generally on the type of information used by skilled players to facilitate decision-making. These findings have also held up in real world occlusion tasks where portions of a volleyball serve have been occluded for the service receiver on a volleyball court (Starkes, Edwards, Dissanayake & Dunn, 1995). Skilled volleyball players extract more information from advance visual cues and are better able to predict landing position of a serve.

More specific information can be gleaned through removal of various features of the display, and this is often accomplished through spatial occlusion of certain elements. For example, Abernethy and Russell (1987) showed that in badminton, when the arm and /or racquet was occluded during a display, the decision accuracy of the experts decreased to a level below that exhibited by the novice performers, showing the racquet to be a critical feature underlying the expert advantage.

A number of researchers have combined eye movement recording techniques with temporal or spatial occlusion studies to gain a more precise picture of the nature of visual cues underlying the decision processes of experts (e.g., Helsen & Starkes, 1999; Goulet et al., 1989; Savelsburgh et al., 2002). Goulet et al. (1989) found that eye movements preceding decisions were focused on the shoulder and trunk area for skilled performers in tennis in comparison to the head for the less skilled performers (see also Singer, Cauraugh, Chen, Steinberg & Frehlich, 1996). Subsequent temporal occlusion in a second experiment showed that high accuracy levels could be maintained for the skilled performers even under situations where information was only available from the preparatory stage of the movement.

One of the benefits of eye movement data is that a dynamic picture of the visual search patterns of skilled performers is provided as the action unfolds (Ward, Williams & Bennett, 2002). It has generally been shown that skilled performers show relatively fewer fixations than novice performers (e.g., Abernethy, 1985), and that fixations are qualitatively different, with experts directed to areas of the display that are believed to be most informationally-rich. A reduction in the number of fixations for skilled rather than less skilled performers is in keeping with proposals that experts extract more information from one fixation than novices, due to mechanisms of chunking (see also Ripoll, Kerlizin, Stein & Reine, 1995; Starkes & Allard, 1991). More recently the smaller number of fixations by experts has been linked to the idea of a perceptual pivot (see Huys & Beek, 2002; Williams & Davids, 1998; Williams & Elliott, 1999), where eye position is anchored enabling a wide field of search of peripheral features; and second, to periods of 'quiet eye' associated with movement preparation and a reduction of variability in the motor system (Vickers, 1996).

However, perhaps not surprisingly, visual search patterns can be relatively domain specific. Williams, Davids and Burwitz (1994) showed that in 11 vs 11 soccer situations expert players showed more fixations (i.e., an increased search rate) than the less skilled players, focusing on peripheral aspects of the display, including the position of other players, in comparison to novice performers who tended to track the ball. Helsen and Pauwels (1993) also showed a difference in visual search patterns depending on the defensive or offensive nature of the decision (for a detailed review of the eye movement data see Cauraugh & Janelle, 2002; Williams et al., 1999; Williams, 2002).

While eye movement fixations are potentially useful sources of information for determining the critical features underlying expert decisions, the validity of these methods has been questioned and the combination of multiple techniques to understand which cues afford the expert advantage has been recommended (e.g., Williams et al., 1999). For example, Ward, Williams, and Bennett (2002) removed all contextual cues from a tennis opponent by converting major joint centers into point light sources to determine whether the expert advantage in tennis was dependent on these cues. In keeping with previous literature, the relative motion information of the major joint centers displayed by the point lights provided enough information to show differences as a function of skill and visual search behaviors did not differ across normal video and point-light displays. The conversion of data into minimal directional units of x and y coordinates affords easy editing and also enables the application of statistical data-reduction techniques, such as principal component analysis to aid in uncovering the common variance between the players and the ball. This analysis technique has been used by Post, Daffertshofer and Beek (2000) to examine change over time in the acquisition of three-ball juggling, and Beek, Jacobs, Daffertshofer and Huys (2003) have recommended using this technique to gain a further understanding of the control processes underlying expert performance. In summary, if the question is to determine the nature of the structural information underlying the expert advantage, especially in high dimensional, team sports, a combination of the above techniques is believed to help understand *what* information is processed, in addition to *how*.

Perceptual training. From a practical standpoint, there has been considerable interest in the implications of the above findings for the training of perceptual skill (see Williams & Ward, 2003; Williams et al., 2004). Williams, Ward, Knowles and Smeeton (2002), successfully improved the response time of tennis players, both in the laboratory and in the field, after perceptual-skills training interventions. While this research has important implications for training and improving tactically-based decisions, the need to maintain the perception-action links during training has repeatedly been emphasized, in as much as the effectiveness of a decision is dependent on the associated accuracy and speed of the execution (i.e., motor efficiency). The need to maintain a degree of flexibility in the nature of the perceptual information affording action has also been recommended, at the expense of specific, prescriptive instruction methods and techniques that fail to provide sufficient variation in practice (see Beek et al., 2003). It is important to note that to date the effects of perceptual training have only been assessed in terms of immediate performance improvement and short-term retention. The long-term retention of performance improvements as a result of perceptual training have not been determined.

Recall and recognition. Recall and recognition paradigms, in addition to verbal reports, have alerted researchers to the memory structures and processing strategies underlying skilled performance (i.e., anticipation and decision-making) in sport. These methods were based on the work of de Groot (1965), Charness (1976, 1979) and Chase and Simon (1973) in chess. Chase and Simon (1973) showed that experts in chess could be differentiated on their fast and accurate ability to perceive and recognize structured patterns of play, but not random placement of chess pieces. This finding highlighted the importance of domain-specific experience, rather than natural abilities associated with IQ and superior memory in general, underlying expertise. In sport, the historical and common attribution of performance to indices associated with talent, rather than experiential factors, meant that paradigms similar to that of Chase and Simon's could illuminate on the various contributions of domain-specific skills acquired as a result of practice.

Even though sports are often not perceived as highly cognitive in nature as chess, researchers have shown that strategic differences related to domain-specific knowledge structures, which have been coined 'software' features, rather than physical 'hardware' features, consistently differentiate across skill in sport (Starkes & Deakin, 1984). Recall of structured game sequences is better for high-level rather than low-level performers, across a variety of sports and with a variety of mediums (e.g., Abernethy, Neal & Koning, 1994; Allard, Graham & Paarsalu, 1980; Borgeaud & Abernethy, 1987; Garland & Barry, 1990; Helsen & Pauwels, 1993; Nakagawa, 1982; Starkes, 1987; Starkes & Deakin, 1984; Williams, Davids, Burwitz & Williams, 1993; Williams & Davids, 1995); incidental recognition tests of previously viewed structured game plays are improved for skilled rather than less-skilled performers (e.g., Allard et al., 1980; Garland & Barry, 1990; Williams & Davids, 1995; Williams et al., 1993); and domain-specific perceptual tests reliably differentiate expert and novice performers, in comparison to perceptual tests associated with physical features, such as static and dynamic visual acuity, simple visual RT, and central-peripheral awareness (e.g., Abernethy et al., 1994; Helsen & Starkes, 1999; Starkes, 1987; Ward & Williams, 1999). Indeed, Reilly, Williams, Nevill and Franks (2000) showed that anticipatory skill, related to domain-specific experience, was one of four important predictors of skill level among teenage soccer players, in addition to speed and agility. While physical skills quite understandably differentiate across skill in sport, factors related to perceptual skill and cognitive development are, at least, equally important. Ward and Williams (1999) have also shown that these cognitive skills are acquired somewhat irrespective of cognitive development and maturational age (see also Abernethy, 1988). The degree of modification of cognitive abilities with practice has been the focus of much of the current expertise research in sports, as we detail later.

The ability to chunk information into meaningful wholes or patterns of tactical significance, via detailed and extensive task-specific memory structures, has been proposed to underlie early and accurate decision making performance in sports (see Tenenbaum, 2003; Williams, et al. 1999), rather than merely being a consequence of experience with the game. For example, Williams and Davids (1995) showed that only skilled players, not physically disabled spectators matched for perceptual experience, showed superior recall on game structured scenarios. Likewise, Allard, Deakin, Parker and Rodgers (1993) showed that coaches, athletes and referees in basketball were differentially more skilled on those cognitive tasks that more directly tapped their role in the sport (i.e. referees were superior on tasks related to recognition and naming of violations, coaches better at recognizing schematic plays, etc.). Nevertheless, anecdotal information from coaches and certain other researchers (see Smeeton, Ward & Williams, 2004) suggests that some transfer of perceptual skill is seen across sports with similar perceptual demands. Finally, high correlations between decision accuracy and recall (e.g., Helsen & Starkes, 1999) suggest that the memory structures associated with each underpin the expert perceptual-cognitive advantage in sport.

The nature of knowledge and control structures. Performance differences between experts and novices for cognitive and perceptual-motor skills have traditionally been explained using terminology derived from Anderson's ACT (Active control of thought, 1982, 1983) or also termed, production-system theory of skill acquisition (see French & Thomas, 1987; McPherson & French, 1991; McPherson, 2000; McPherson & Kernodle, 2003; Starkes & Allard, 1991). Accordingly, early in practice, declarative rules or knowledge structures underlie the slow and effortful decision-making of novice performers. With practice, these rules become compiled into efficient productions, such that certain conditions evoke actions without the necessity for intervening processes associated with the bringing to mind of domain-specific, verbalisable knowledge. Based primarily on analysis of verbal protocols (see Ericsson & Simon, 1980) of children and adults in sports such as tennis and basketball, McPherson, French, Thomas and colleagues have shown how factual knowledge (i.e., what to do) develops along with procedural knowledge (i.e., how to do) and that skilled performers' plans, based on verbalizable goals, become transformed into more specific 'if-then-do' or 'condition-action' rules. These rules are then refined and improved as a function of extended practice, such that they become specific to the task and more tactical in nature as skill improves.

If knowledge does indeed become proceduralized as a function of skill and supposedly non-verbalizable, then issues are raised with respect to the validity of verbal reports for skilled performers (see Abernethy, 1993, 1994). Additionally, while production-based terminology was formulated based on observations of change in cognitive-domains, such as learning a computer language, in motor skills, productions are no longer merely linked to the decision side but are highly dependent on execution. Therefore, motor-based productions are likely to be of quite a different nature to the internal representations governing the manipulation of thought. Although this issue has been addressed in the work of McPherson and colleagues (e.g., McPherson & Thomas, 1989), whereby response selection has been differentiated from execution, the highly cognitive based level of explanation for these expertise effects might be over-stretched.

Production-based terminology and ideas have also been incorporated in recent research designed to examine notions of automaticity. The procedural, or automatic stage of performing, whereby responses are executed without the need for problem solving and complex decisions, has been examined in relation to the nature of the control processes underlying skilled performance in golf and soccer (see Beilock et al., 2003; Beilock & Carr, 2004, for reviews). Beilock and colleagues have shown that manipulations, designed to encourage attention to aspects of performance that are believed to have become proceduralized (e.g., the dominant foot in soccer dribbling), cause decrements in performance in skilled athletes. These authors have argued that a control focus, characteristic of an earlier, less effective and more declarative level of performance, interferes with the procedural skill and hence control structures governing performance at high levels of skill. Indeed, while skilled performers are affected by this focus, novice performers are not.

The interpretation of these effects in production system terminology, however, has been questioned. Perkins-Ceccato, Passmore and Lee (2003) showed interactions of skill-level with attentional focus in a golf putting task, whereby skilled golfers became more variable in their performance under focus manipulations designed to encourage attention to their arms and the swing, but not to the club, whereas the reverse was true for the novice performers. Rather than proceduralisation of knowledge being responsible for these skill by attentional-focus interactions, another explanation might be found from theories and approaches that place less emphasis on cognitive processes and more on self-organising principles operating within the motor system. Bernstein (1950s/ 1996) originally discussed the motor system in terms of distinct levels of control that interact on many levels but change in their control function as practice progresses and skill develops. Accordingly, skill and associated notions of automaticity are linked to the devolvement of control processes to lower levels of the action system (e.g., muscular-articular synergies), that can operate somewhat independently from higher levels (e.g., action plans), and that do not require cognitive involvement for efficient and effective results. Breakdowns in performance, therefore, may be a result of inappropriate levels of the motor system taking control of the movement (see also Beek, 2000).

Cognitive structures or the education of perception? Highly cognitive information processing explanations for the expert advantage in sport, which rely heavily on internal representations and cognitive processes mediating stimulus interpretation and action choice, have also been questioned by researchers influenced by the work of Gibson (1979) in ecological psychology (see Beek et al., 2003; Huys, Daffertshofer & Beek, 2004). According to these researchers, learning and hence skilled performance is seen as a process of 'educating attention', whereby specific sources of information, which inform action, are identified and functionally coupled to movement as skill progresses. Due to observations of extremely fast modifications to responses on the basis of vision during table-tennis and the long jump, for example (Bootsma & van Wieringen, 1990; Lee, Lishman & Thomson, 1982), explanations for skilled performance were based on the tight couplings between perception and action (i.e., compensatory variability), rather than a reduction or change in processing activities. While a reduction in the variability in movements is a common distinguishing characteristic of experts when compared to intermediate performers, it is the qualitative nature of this variability in relation to the task goal that is important, rather than the general amount of variability per se (see Huys et al., 2004). The effective harnessing of variables which are non-functional is a feature of expert performance within the motor system generally, not just with the external environment. In cycling, Bernasconi and Kohl (1993) showed that distinct couplings emerged between respiration and cycle rate, which enabled the skilled performer more economical and effective control of their movements. In runners, Diedrich and Warren (1995) observed no correlation between step cycle and breathing for novice runners, but in expert runners there were specific respiration / step ratios (1:4, 1:3, 2:5, 2:3, 1:1) that were dependent on the tempo and incline of running. Similar, within-system couplings have also been observed in juggling between postural sway and arm movements (Huys et al., 2003). As with cycling and running these system couplings afford greater efficiency and economy in performance.

The importance of practice. While explanations for the nature of the expert advantage in sport might differ with respect to the role of cognition, there is no disagreement across researchers as to the necessity of years of task-specific practice to acquire skilled performance. Research in support of this viewpoint was originally detailed by Ericsson et al (1993). Individual differences across different levels of performance skill were shown to be closely related to deliberate practice hours and hence led the authors to conclude that “many characteristics once believed to reflect innate talent are actually the result of intense practice extended over at least 10 years.” (p363) and that the role of heritability in attainment of high levels of skill might be limited to motivational factors. If one looks across the range of sport studies on practice or deliberate practice there is a correlation (sometimes high, sometimes low) between the *amount* of all types of reported practice and performance and this is consistent with the proposed *relation* between deliberate practice, albeit not equivalent. (Ericsson, 2003).

Perhaps primarily because of enduring beliefs about the role of prior talent and abilities in sport, this proposal has received vibrant interest from researchers working within the sports field. Across a number of sports, ranging from figure skating to wrestling, from hockey to karate, sport-specific practice has been shown to be a significant predictor of skill-based differences in sport (see Starkes, Deakin, Allard, Hodges & Hayes, 1996; Ward, Hodges & Starkes, 2004, for reviews). While these results are encouraging for the theory and speak to the role of practice in modifying physical attributes and skills, there have been reasons to question the ubiquitousness of these findings, particularly when performance and practice differences are examined at an individual level.

Hodges, Kerr, Starkes, Weir and Nanandiou (2004) showed that the amount of variance that could be explained by estimates related to practice was domain specific in swimming and triathlon, such that the distance of the event mediated the amount of variance in performance times which could be explained by practice. In the 100 m and 200 m sprint events in swimming, only approximately 20 % of the variance in times could be explained by practice-related variables, whereas gender accounted for approximately 40 %. As for the 400 m, 1.5 km and triathlon event comprising swimming, cycling and running, these findings were reversed. Gender no longer played an important role in accounting for performance differences, whereas practice accounted for approximately 35 - 40% of the variance in performance times. It would seem that in the shorter, more anaerobic events, physical factors related to height and muscle to body fat ratios limit performance, somewhat independently of practice. This is the first empirical evidence that non-practice specific factors play significant roles in predicting expert performance. It also appears to contradict deliberate practice theory.

Age-based interactions with practice have also been proposed to mediate skill performance such that Côté and colleagues (e.g., Côté & Hay, 1992; Baker, Côté & Abernethy, 2003) argue that it is only after a decision to specialize (around 12 years of age) that sport-specific practice becomes a critical component and predictor of expertise. Before this period, diversity in physical experience and play are presumed to be important for later skill development. Despite these proposals, Hodges et al. (2004) showed a monotonic increase in the yearly amounts of practice for competitive swimmers that was highly related to performance times, even though their average start age was around 6 - 8 years (see also Starkes et al., 1996; Ward, Hodges & Starkes, 2004). Interactions with development have also been explored as a function of ageing. The main finding has been that age-related declines in performance can be circumvented by specific and sustained practice, as evidenced through longitudinal practice records in comparison to cross-sectional comparisons (see Starkes, Weir & Young, 2003, Young & Starkes, in press, for reviews).

Meta-analysis of sport expertise findings

A recent landmark meta-analysis by Thomas, Gallagher and Lowry (2003) is the first to collate and examine sport expertise research. The questions addressed were whether experts and novices differ: on perceptual vs. decision-making aspects of cognition, by level of expertise, by type of sport (team vs. individual), across age levels, according to levels of ecological validity of the test situation, according to levels of internal validity, and by gender. In addition the authors were interested in whether the importance of ecological validity of the skill test varied by level of expertise and whether the importance of perceptual vs. decision-making varied by type of sport.

The authors located 66 published papers, of which 21 were eliminated because they did not include both expert and novice data, another 6 studies lacked sufficient data to calculate effect size. Thirty-nine studies published between 1987 and 2002, or 87% of the literature available were included. The meta-analysis included data on 1,112 experts and 1,287 novices. Perceptual and cognitive skills were found to be equally important in predicting expert performance in athletes. It appears that perception and decision-making are both critical aspects of individual sport; however, cognitive skill was slightly more important for team sport experts. The same findings hold true regardless of gender. In terms of design, adult expert-novice differences are typically larger than for those found in children and adolescents and perhaps not unexpectedly level of experience influences the extent of expert-novice differences. When the expert group is comprised of international, national or college-level athletes, differences across skill class are more likely to be observed than when the elite group is comprised of developmental-level athletes, such that national, international and college level athletes are better than developmental level athletes or others . Finally, greater ecological validity of the perception / decision task produced higher effect sizes for experts and novices, but it was a more important factor for higher levels of performance. The more expert you are as a performer, the more important ecological validity of the task becomes in assessing your performance.

On the basis of this analysis a number of recommendations can be made for future research. It is important that the research setting and technique focus on capturing the *basis* for superior performance, in terms of either the process of acquisition or cognitive structure involved. It is very important in sport research to be specific and define the level of expertise / performance one is studying, both in terms of years of experience but also in level of competition and performance attained. In terms of perceptual skill, adult high performance athletes appear to focus attention on specific informative areas of a game and as a result they exhibit better recognition of game structure and better recall of game elements. In contrast, young athletes typically lack the knowledge to produce quality solutions and are unable to reliably separate relevant from irrelevant information. An interesting suggestion by the authors is that those children who become experts at relatively young ages have clearly derived *more from practice* than others. This is an important point worthy of future study.

This chapter provides an overview of the major approaches in sport expertise research. The complexity of this area is shown in the multiple research paradigms that have been applied, from visual search and decision-making, to verbal protocol analysis, and from an examination of the automatic nature of performance, to the role of cognition. We have also presented different major theoretical approaches represented by cognitive and ecological psychology, with implications for skill training. The importance of practice to both of these approaches is shown in the section reviewing research on practice features in the acquisition of sport expertise. Bringing all of this research together, we discussed the meta-analysis of Thomas et al., (2003) which provides some directions for future research. While the Thomas et al. meta-analysis demonstrates great consistency in many of the findings related to sport expertise, it is clear from the issues outlined earlier that we have far to go in understanding skilled performance in sport. Certainly expert sport performance is not a unitary entity but a complex interaction of perception, decision-making and movement skill, as well as one's roleand the nature of sport engaged in. The inherent complexity of sport, yet real world application, is both an intriguing quality and one that makes the domain ripe for research.

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