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Cognitive psychology in sport: Progress and prospects☆

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A B S T R A C T

Problem: There has been a recent upsurge of research interest in cognitive sport psychology or the scientific study of mental processes (e.g., mental imagery) in athletes. Despite this interest, an important question has been neglected. Specifically, is research on cognitive processes in athletes influential *outside* sport psychology, in the "parent" field of cognitive psychology or in the newer discipline of cognitive neuroscience?

Objectives: The purpose of this paper is to explore the theoretical significance of research on expertise, attention and mental imagery in athletes from the perspective of cognitive psychology and cognitive neuroscience.

Method: Following analysis of recent paradigm shifts in cognitive psychology and cognitive neuroscience, a narrative review is provided of key studies on expertise, attention and mental imagery in athletes.

Results and conclusions: This paper shows that cognitive sport psychology has contributed significantly to theoretical understanding of certain mental processes studied in cognitive psychology and cognitive neuroscience. It also shows that neuroscientific research on motor imagery can benefit from increased collaboration with cognitive sport psychology. Overall, I conclude that the domain of sport offers cognitive researchers a rich and dynamic natural laboratory in which to study how the mind works.

Over the past two decades, there has been a proliferation of research interest in cognitive sport psychology or the scientific study of mental processes in sports performers (see Abernethy, Maxwell, Jackson, & Masters, 2007; Moran, 1996, for brief accounts of this field). This welcome trend is evident in the abundance of recent studies on cognitive processes such as anticipation (Aglioti, Cesari, Romani, & Urgesi, 2008), attention (Milton, Solodkin, Hlustik, & Small, 2007), expertise (Müller, Abernethy, & Farrow, 2006), judgement and decision making (Bar-Eli & Raab, 2006), memory (Katinka, MacMahon, & Mine, 2008), mental imagery (MacIntyre & Moran, 2007a, 2007b), and perception (Memmert & Furley, 2007) in athletes. At first glance, this impressive range of topics bears ample testimony to a thriving field. On closer inspection, however, an important issue arises. Is research on cognitive processes in athletes influential *outside* sport psychology – for example, in the *parent* field of cognitive psychology or in the newer discipline of cognitive neuroscience, which seeks to explain cognitive processes in terms of brain-based mechanisms (Ward, 2006)? As far as I know, there has been no attempt to analyse the signficance of cognitive sport psychology in facilitating the common goal of contemporary cognitive psychology and cognitive neuroscience – that is, to understand how the mind works. Filling this gap in the literature, the present paper explores the theoretical significance of selected research on cognitive processes in athletes from the perspective of these latter two cognitive sciences. In accordance with the theme of this special FEPSAC anniversary issue, I will highlight, where possible, the contribution of European researchers to the study of cognition in sport. In order to achieve my objective, the paper is organised in three sections as follows. First, I shall explain why, in recent years, enthusiasm has largely replaced indifference in cognitive researchers' attitude to sport as a suitable domain for the study of mental activity. Then, I shall consider, briefly, research in three areas of cognitive sport psychology – expertise, attention and mental imagery – to show how cognitive psychologists' and cognitive neuroscientists' theoretical understanding of mental processes has improved or can improve as a result of studies conducted on athletes. To conclude, I shall sketch some potentially fruitful new theoretical directions for research on cognition in sport.

Cognitive psychology and sport: from indifference to enthusiasm

Historically, cognitive psychologists have largely ignored the domain of sport in their quest to understand how the mind works.

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To illustrate, the subject indices of most textbooks in this field – even those on *applied* cognitive psychology (e.g., Herrmann, Yoder, Gruneberg, & Payne, 2006) – contain few, if any, references to terms such as "sport" or "athlete". This neglect is surprising because competitive sport offers researchers the opportunity to study basic cognitive processes such as attention, memory, knowledge acquisition and visual search (Abernethy et al., 2007), as well as expertise in the performance of complex skills and movements under severe time constraints and in rapidly changing environments. Less formally, sport has played a seminal role in the formation of at least one key cognitive construct - the idea of motor *schemata* developed by the British psychologist Sir Frederic Bartlett in his book *Remembering* (Bartlett, 1932). Imbued with a lifelong passion for cricket, Bartlett marvelled at the ingenuity with which batsmen shaped their strokes in anticipation of bowlers' intentions. Watching cricket led to Bartlett's theory of schemata:

> "Suppose I am making a stroke in a quick game, such as tennis or cricket. How I make the stroke depends on the relating of certain new experiences, most of them visual, to other immediately preceding visual experiences and to my posture, or balance of postures, at the moment … When I make the stroke I do not, as a matter of fact, produce something absolutely new, and I never merely repeat something old. The stroke is literally manufactured out of the living visual and postural 'schemata' of the moment and their interrelations" (Bartlett, 1932, pp. 201–202).

Unfortunately, Bartlett's passion for sport was not shared by his successors in cognitive psychology. Indeed, since the foundation of this field in the 1950s, there has been a dearth of references to athletic pursuits in textbooks on cognition. This oversight is regrettable as it may convey the misleading impression that sport is a frivolous pursuit, unworthy of serious academic scrutiny. Happily, this neglect of sport has changed considerably as a consequence of certain paradigm shifts in cognitive psychology and cognitive neuroscience. These can be summarised as follows.

To begin with, within cognitive psychology, there has been a growing disenchantment with the information processing paradigm that has dominated the field since its inception. In particular, critics object to the idea that the mind is a rational computational system that operates largely independently of emotional factors or bodily experiences. Thus Claxton (1980) caricatured cognitive psychology when he claimed that its typical participant "does not feel hungry or tired or inquisitive; it does not think extraneous thoughts or try to understand what is going on. It is, in short, a computer" (p. 13). More recently, other limitations of the information processing paradigm have been exposed. These limitations concern the relative neglect of both emotional and motor processes by cognitive researchers. To explain, historically, emotional processes did not fall within the scope of cognitive psychology. However, as there is now compelling evidence that emotional factors influence cognitive processing (e.g., mood can influence memory; Smith & Kosslyn, 2007), these processes are becoming more central to the field. Another weakness of the information processing paradigm is that it has neglected the mind's motor output in favour of its sensory input (Smith & Kosslyn, 2007). Again, this oversight has long been evident. For example, more than two decades ago, Adams (1987) observed that cognitive psychology is "preoccupied with disembodied perceptions and higher processes, and indifferently concerned with translating perceptions and higher processes into 'action'" (p. 66).

Turning to the present day, as the information processing paradigm fails to explain adequately "how cognition interfaces with perception and action" (Barsalou, 2008, p. 620), alternative conceptual approaches have been postulated. For example, Barsalou's (2008) theory of *grounded cognition* emphasizes the constant interaction between perception, action, the body and the environment. This interaction is held to be governed by the principle of 'simulation' or "the reenactment of perceptual, motor, and introspective states acquired during experience with the world, body, and mind" (Barsalou, 2008, p. 618; see also Markman, Klein, & Suhr, 2009). To illustrate this principle, consider action observation and movement planning. Briefly, research shows that when we watch someone performing an action that is within our motor repertoire, our brains simulate performance of that action (Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005). Mental simulation processes also occur during motor imagery – a phenomenon which involves the "imagining of an action, either covertly or explicitly, without necessarily executing the action" (Witt & Proffitt, 2008, p. 1480). I shall return to this topic later in the paper. Whether used in action observation or in mental imagery, mental simulation is a key construct in *motor cognition* – the study of how the mind plans and produces skilled actions and movements. More precisely, this field is concerned with the "preparation and production of actions as well as the processes involved in recognizing, anticipating, predicting and interpreting the actions of others" (Jackson & Decety, 2004, p. 259). Clearly, motor cognition offers a fruitful theoretical paradigm for cognitive sport psychology because it not only acknowledges the inextricable link between cognition and action but also highlights the importance of bodily knowledge and kinaesethetic processes in the study of mental activity (Moran & MacIntyre, 2008).

A similar, if more subtle, paradigm shift to that which occurred in cognitive psychology is also detectable in cognitive neuroscience. Specifically, whereas researchers in this latter field initially studied mental processes by exploring cognitive deficits in clinical populations (e.g., patients with brain damage), they are now beginning to investigate the neural substrates of cognition in action by focusing on highly skilled, often elite, participants, such as athletes (Aglioti et al., 2008) and dancers (e.g., Cross, Hamilton, & Grafton, 2006). This gradual change from a "deficit-based" approach to a "strength-based" approach to certain aspects of cognition (e.g., mental imagery; see Moran & MacIntyre, 2008) has led to an upsurge of neuroimaging studies of athletic expertise. For example, Aglioti et al. (2008) used transcranial magnetic stimulation (TMS; a technique in which a magnetic coil is placed over the scalp either to stimulate or to inhibit selectively certain areas of the cortical surface) to identify the neural mechanisms underlying action anticipation in professional basketball players. They found that expert players predicted the success of free shots in basketball earlier and more accurately than did people with comparable visual experience (coaches and sports journalists) and novices. Because the basketball players exploited advanced kinematic cues in the task, Aglioti et al. (2008) concluded that expert athletes have developed fine-tuned "resonance" mechanisms that enable them to simulate and predict other players' actions. In a similar vein, neuroimaging studies have been conducted using golfers (Milton et al., 2007), high jumpers (Olsson, Jonsson, Larsson, & Nyberg, 2008) and tennis players (Fourkas, Bonavolontà, Avenanti, & Aglioti, 2008; Wright & Jackson, 2007). Unfortunately, as I shall explain later in the paper when reviewing motor imagery research, some neuroscientific studies of sports performers are hampered by questionable theoretical assumptions and methological practices (e.g., the use of confusing and inadequately validated instructions for participants).

In summary, against the background of paradigm shifts in psychology and neuroscience, research in cognitive sport psychology is now well-placed to profit from increased theoretical interest in the neural substrates of expert motor cognition. The conclusion is clear. Far from being perceived as a trivial pursuit, sport is now believed to offer cognitive researchers from different disciplines a rich and dynamic natural laboratory for the study of how the mind works. Despite such progress, there is still uncertainty among cognitive scholars as to the most suitable theoretical paradigm to adopt in studying mental processes in sport. I shall consider this issue briefly at the end of the paper. Having sketched the relationship between cognitive sport psychology and cognitive psychology, I shall now explore the significance of three cognitive topics - expertise, attention and mental imagery. Due to space limitations, however, discussion of these topics will be necessarily brief.

Expertise

Expertise is the growth of specialist knowledge and skills as a result of effortful experience and is currently a "hot topic" both in cognitive psychology and sport psychology. It has attracted special editions of academic journals such as *Journal of Experimental Psychology: Applied* (Ericsson & Williams, 2007) and *Applied Cognitive Psychology* (Ericsson, 2005), an extensive handbook (Ericsson, Charness, Feltovich, & Hoffman, 2006), an entire section of the *Handbook of Sport Psychology* (Tenenbaum & Eklund, 2007), and interest from popular science (e.g., see Ross, 2006, in *Scientific American*). The increasing importance of research on expertise in sport psychology is illustrated by the fact that the whereas the first edition of the *Handbook of Sport Psychology* (published in 1993) had no chapter coverage of this topic, the second edition (in 2001) had one chapter and the third edition (2007) had *five* chapters on it. For cognitive psychologists, research on expert-novice differences in sport is important because it provides a window on knowledge-based perception. Specifically, it can reveal the role of cognitive processes in mediating the relationship between visual perception and skilled action in dynamic yet constrained environments. For psychologists, the study of athletic expertise (see reviews by Hodges, Starkes, & MacMahon, 2006; Williams & Ford, 2008) presents at least two intriguing challenges. Theoretically, it raises the question of how certain people (such as elite athletes) manage to circumvent information processing limitations when performing complex motor skills. Methodologically, it poses the challenge of developing objective and valid measures of expert-novice differences. I shall now examine briefly how cognitive sport psychologists have addressed these challenges.

To begin with, let us consider a question that Bartlett (1947) raised from his observation of top-class cricket. How do expert batsmen appear to have "all the time in the world" (p. 836) as they face rapidly bowled balls? Expertise researchers have explored the cognitive mechanisms that enable skilled athletes to respond effectively to fast-moving balls, thereby overcoming seemingly "hard-wired" limitations imposed by neural delays in reaction and movement times. For example, Müller et al. (2006) conducted experiments on the ability of world-class cricket batsmen to anticipate, from advance cues, the nature and "length" (i.e., probable landing position) of balls delivered to them by bowlers using either speed or spin bowling techniques. Typically, cricket bowlers try to 'dismiss' batsmen by using either rapidly-paced ball deliveries or slower, spin-based deliveries that bounce awkwardly when the ball hits the pitch. Müller et al. manipulated the predictive information available to the batsmen using various occlusion methods (whereby potentially important information is systematically disguised or removed). Results showed that for the fastest-bowled deliveries, batsmen of all skill levels relied on advance cues extracted from ball flight information to anticipate bowlers' intentions. In addition, Müller et al. discovered that compared to their less skilled counterparts, the highly skilled players demonstrated a unique ability to pick up *earlier* advance cues from their opponents' bowling arm and hand. Less skilled batsmen did not seem to be aware of this latter source of information. Based on such research (see also Aglioti et al., 2008), it seems that the ability to extrapolate accurately from the information yielded by advance cues is a vital mechanism enabling expert athletes to anticipate the trajectory and likely landing point of rapidly approaching balls.

Theoretically, the preceding findings suggest that expert athletes in fast-ball sports appear to have a *cognitive* (knowledge-based) rather than a physical advantage over less skilled counterparts. Supporting this conclusion, research has shown repeatedly that expert athletes do not possess faster reaction-times than members of the general population. What is not clear, however, is how and at what stage of expertise early anticipatory cue-utilization skills are acquired and whether or not such skills can be "fast-tracked" through special training programmes. Another intriguing issue in athletic expertise is how elite performers manage to solve complex "multi-tasking" problems so efficiently. Eccles (2006, 2008) investigated expertise in orienteering, a sport that tests people's ability to navigate a given distance as fast as possible in a wild terrain using only a map and a compass. The cognitive challenges of this sport are daunting. To illustrate, when competing, orienteers are required to engage in simultaneous tasks, such as map-reading while running. In order to reduce such information processing demands, expert orienteers use a variety of strategies that change the way in which task-relevant information is presented. For example, folding the map reduces the amount of information that orienteers have to pay attention to and *thumbing* it (i.e., keeping their thumbs on the section of the map that they are following) minimize visual search time. Theoretically, what is interesting about Eccles' research is that it shows how expert athletes may sometimes use *external* tools to reduce mental workload in competitive situations, a phenomenon that has been largely ignored by cognitive psychologists who adhere to the information processing paradigm.

Turning to the methodological challenge of expertise research, considerable progress has been made in the development of suitable performance measures. Driving such measures is the *expert performance approach* (Ericsson & Smith, 1991; Ericsson & Ward, 2007; Williams & Ericsson, 2005) - a model that postulates three main tasks in the study of expertise in domains such as sport. The first task is to capture expert performance objectively using laboratory (e.g., life-size video film simulations displayed on large screens) and field (e.g., match analysis) techniques. The second task is to use a variety of "process tracing" (Williams & Ericsson, 2005, p. 286) measures such as eye-tracking technology, event related potentials and verbal reports in an effort to identify possible mediating mechanisms underlying expertise. Although these measures do not assess the "process" of expertise directly, they enable inferences to be drawn about what skilled athletes attend to, and report thinking of, when tackling actual problems or plausible simulations within their specialist domain. The final task of the expert performance approach is to understand how expertise is acquired and modified through learning and practice. To address such issues in sport, longitudinal studies on the practice history and strategies of elite athletes are required. Unfortunately, as Williams and Ericsson (2008) noted, "questions about how world-class athletes focus their attention during practice, how they practice … and how they seek feedback are rarely addressed in contemporary literature" (p. 660).

Of the three tasks specified by the expert performance approach, the most relevant for the present paper is that which attempts to elicit the cognitive mechanisms underlying expertise. In this regard, eye-tracking technology has been especially helpful in identifying expert-novice differences in visual perception in sport (see Hodges et al., 2006). Typically, studies in this field have compared the visual search behaviour of two samples of participants engaged in simulated performance in a given sport. These samples comprise *experts* or elite performers and *novices* or relative beginners. Using this group comparison paradigm, investigators have discovered that, in general, expert athletes tend to display more efficient search strategies than novices when inspecting sport-specific visual displays in dynamic activities such as soccer (Vaeyens, Lenoir, Williams, Mazyn, & Philippaerts, 2007), as well as in relatively static activities such as golf putting (Campbell & Moran, 2005). In general, proficient athletes tend to display fewer visual fixations than novices while engaged in their specialist sport skills, but these fixations are often of longer duration than those of their less skilled counterparts. There are also consistent qualitative differences in visual search behaviour between these groups with experts tending to fixate more than novices on "information rich" areas of the visual display in question (Hodges et al., 2006). Taken together, such findings suggest that expert athletes have more refined knowledge bases and make more effective use of information from the visual field than do relative novices (Williams & Ford, 2008). It is still not clear, though, how athletic experts acquire, refine and update their sport-specific knowledge base over time.

Attention

Research on attention, or the "process of concentrating on specific features of the environment or on certain thoughts or activities" (Goldstein, 2008, p. 100), is central to cognitive sport psychology because the ability to exert mental effort effectively is vital for optimal athletic performance (Moran, 2009). Attentional research is also one of the fastest growing fields in cognitive psychology and cognitive neuroscience because it investigates the mechanisms by which "voluntary control and subjective experience arise from and regulate our behaviour" (Posner & Rothbart, 2007, p. 1). Nevertheless, despite more than a century of research in this field, there is still a great deal of confusion about the nature of, and cognitive mechanisms underlying, attention. In this regard, Pashler (1999) claimed that "no one knows what attention is … there may not be an 'it' to be known about" (p. 1). Nevertheless, in sport, attentional lapses, in which performers' concentration becomes disengaged momentarily from the task at hand, are all too real for some athletes. To illustrate, consider how Matthew Emmons, the American 50 m three-position rifle shooter, missed an opportunity to win a gold medal at the 2008 Olympic Games in Beijing by inadvertently pulling the trigger at the wrong time on his last shot, possibly due to anxiety. Afterwards, he revealed that he had felt "a little bit more nervous" (Matuszewski, 2008) and that "I didn't feel my trigger finger shaking but I guess it was" (Isaacson, 2008). Remarkably, an attentional lapse on his last shot had also deprived him of an Olympic gold medal at the previous Games in Athens in 2004. Emmons' unfortunate experience in Beijing raises an important question which, as explained earlier, has been largely neglected in cognitive psychology. How do emotions, such as anxiety, affect attentional processes? One way in which cognitive sport psychologists have addressed this question in the laboratory is by exploring visual perceptual aspects of the phenomenon of *choking under pressure* or the acute failure of normally expert skills under conditions of increased anxiety. For example, Vickers and Williams (2007) investigated the relationship between workload, arousal and the visual attentional processes of elite biathlon shooters under conditions of low- and high-pressure. One of their findings was that, for these shooters, a relatively long duration of final fixation on the target (known as the 'quiet eye' period) was associated with less choking as physiological arousal increased. More generally, an interesting feature of the choking phenomenon is that it seems to involve a motivational paradox. Specifically, the more effort the choking performer expends in trying to do well, the more the performance deteriorates. Unfortunately, until recently, research in this field has been hampered by its rather atheoretical approach. As a result, there has been little progress in understanding the cognitive mechanisms that underlie the relationship between anxiety and attention. However, with the advent of "processing efficiency theory" (PET; Eysenck & Calvo, 1992), and its successor "attentional control theory" (ACT; Eysenck, Derakshan, Santos, & Calvo, 2007), theoretical relationships between anxiety, working memory (a cognitive system that regulates the storage and manipulation of currently relevant information) and skilled performance can be tested more precisely. For a recent review of this topic in sport psychology, see Wilson (2008).

Briefly, processing efficiency theory distinguishes between processing *effectiveness* (the quality of task performance) and processing *efficiency* (the relationship between the effectiveness of performance and the effort or resources that have been invested in task performance). It predicts that the adverse effects of anxiety on performance effectiveness are often *less* than those on processing efficiency. This prediction stems from the assumption that increased effort by the performer can compensate for the reduction in attentional resources that are typically caused by anxiety. In general, this prediction has been corroborated empirically in sport psychology (e.g., Wilson, Smith, Chattington, Ford, & Marple-Horvat, 2006). An interesting feature of PET is its assumption that the effects of anxiety on performance are mediated by the *central executive* component of working memory (i.e., the hypothetical control system that regulates attentional processes). However, PET does not pinpoint precisely which aspects of working memory are most adversely affected by anxiety. In attentional control theory (ACT), however, Eysenck et al. (2007) postulate that anxiety specifically affects the *inhibition* function of the central executive, which controls people's ability to resist disruption or interference from distractions. This prediction could be tested by investigating the degree to which anxiety affects athletes' gaze behaviour when faced with relevant and irrelevant visual stimuli.

Mental imagery

One of the most remarkable capacities of the mind is its ability to mimic experience. For over a century, researchers have investigated mental imagery or the process by which we can represent information in our minds in the absence of appropriate sensory input. Among athletes, a key application of this process is 'mental practice' (MP) or the systematic use of mental imagery processes to rehearse a movement or skill symbolically. An extensive body of research shows that MP is helpful for the learning and performance of motor skills (e.g., see Driskell, Copper, & Moran, 1994; Morris, Spittle, & Watt, 2005). Imagery-based techniques are also widely recommended as intervention procedures for the development of psychological skills (e.g., concentration; Kremer & Moran, 2008).

Until the 1980s, the mechanisms underlying mental imagery were largely unknown. However, important theoretical progress on this issue occurred with the discovery that imagery shares some neural pathways and mechanisms with like-modality perception (Farah, 1984; Kosslyn, 1994) and with the preparation and production of motor movements (Jeannerod, 2001). This postulated overlap of neural representations between imagery, perception and motor execution is known as the "functional equivalence" hypothesis (e.g., Finke, 1979; Jeannerod, 1994). To illustrate, Johnson (1982) investigated the effects of imagined movements on the recall of a learned motor task and concluded that "imagery of movements has some functional effects on motor behaviour that are in some way *equivalent* [italics added] to actual movements" (p. 363). Other studies (e.g., Roland & Friberg, 1985) suggested a functional equivalence between imagery and perception because "most of the neural processes that underlie like-modality perception are also used in imagery" (Kosslyn, Ganis, & Thompson, 2001, p. 641).

The functional equivalence hypothesis offers a bridge between cognitive sport psychology and cognitive neuroscience. However, if this bridge is to allow research "traffic" to flow in either direction between these disciplines, it must be built on firm theoretical and methodological foundations. Unfortunately, questions can be raised about the validity of cognitive neuroscientists' understanding and measurement of motor imagery processes in athletes. For example, consider Decety's (1996) proposal that motor imagery "corresponds to the so-called internal imagery (or first person perspective) of sport psychologists" (p. 87). This idea is endorsed by Jeannerod (1997) who distinguished between visual or "external" imagery and motor imagery, which is "experienced from within, as the result of a 'first-person' process where the self feels like an actor rather than a spectator ('internal' imagery)" (p. 95). Although intuitively appealing, these suggestions by Decety (1996) and Jeannerod (1997) have been challenged by imagery researchers in cognitive sport psychology. As Morris et al. (2005) pointed out, *imagery perspective* (external or internal) refers to whether imagery is experienced from outside or inside of one's body – it does not designate a particular type or modality of imagery (visual or kinaesthetic). Put simply, "kinaesthetic and internal imagery are not the same and visual and external imagery are not the same" (p. 132). Indeed, there is evidence that people can form kinaesthetic images equally well using either imagery perspective (Hardy & Callow, 1999) and that kinasethetic imagery may have a stronger relationship with an *external* perspective than with an internal one (Callow & Hardy, 2004). Turning to methodological issues, a persistent problem in recent neuroscientific studies of motor imagery in athletes is the use of potentially confusing and inadequately validated instructions/scripts for participants. For example, Olsson, Jonsson, and Nyberg (2008) and Olsson, Jonsson, Larsson, and Nyberg (2008) investigated the effects of internal imagery training in high jumpers. In describing the procedure for the latter study, the authors state that "all through the instruction, an internal perspective was emphasized … the participants understood that it was important to 'feel' like the high jump was executed with no muscular movement *and not to 'see' that the high jump was executed*" (p. 6, [italics added]). Unfortunately, these instructions are confusing for at least two reasons. First, it is well known that instructing people *not* to think about or do something can, under certain circumstances, produce ironic or counter-intentional effects (see Wegner, 1994). In the absence of the imagery compliance and/or manipulation checks that are increasingly required in sport psychology (Cumming & Ramsey, 2009; Morris et al., 2005), how can we be sure that participants did not 'see' themselves executing the high jump? Secondly, in the imagery instructions provided in Olsson, Jonsson, and Nyberg (2008), participants were asked to "imagine that you are running towards the bar". This request can be complied with using an external visual perspective. In summary, the preceding examples show that research on the cognitive neuroscience of mental imagery in athletes could be improved by paying more attention to the findings and methods of cognitive sport psychology. Specifically, neuroscientists investigating imagery processes may benefit from noting that imagery perspective and imagery type should not be confounded (Morris et al., 2005) and that imagery instructions and scripts need to be carefully validated before use (Cumming & Ramsey, 2009). Additional problems arising from the instructions used in neuroscientific studies of motor imagery are considered by Munzert, Lorey, and Zentgraf (in press).

Mental imagery is a multi-sensory construct. Thus Hardy, Jones, and Gould (1996) defined it as "a symbolic sensory experience that may occur in any sensory mode" (p. 28). Unfortunately, most cognitive psychological research in this field has been conducted only on visual imagery. Accordingly, fewer studies are available either on motor imagery (people's ability to simulate or imagine the movements of their bodies in space; McAvinue & Robertson, 2008) or on *kinasethetic* or "feeling-oriented" imagery (but see Callow & Hardy, 2004; Moran & MacIntyre, 1998; Ross, Callow, Hardy, Markland, & Bringer, 2008). This relative neglect of motor imagery is due, in part, to the absence of suitable measures. However, with the development of techniques such as the *mental travel* chronometric paradigm (see review by Guillot & Collet, 2005), it is now possible to investigate motor imagery objectively by comparing the duration required to execute real and imagined actions. The logic here is as follows. According to the functional equivalence hypothesis, imagined and executed actions rely on similar motor representations and activate some common brain areas (e.g., the parietal and prefrontal cortices, the pre-motor and primary cortices; Gueugneau, Crognier, & Papaxanthis, 2008). As the temporal organization of imagined and actual actions is similar, there should be a close correspondence between the time required to mentally perform simulated actions and that required for actual performance. In a typical study, Calmels, Holmes, Lopez, and Naman (2006) examined the temporal congruence between actual and imagined movements in gymnastics. They found that the overall times required to perform and imagine a complex gymnastic vault were broadly similar, regardless of whether participants used "first person" or "third person" imagery perspectives. However, the temporal congruence between actual and imagined actions is mediated by a number of factors. For example, Guillot and Collet (2005) concluded that when the skills in question are largely automatic (e.g., reaching, grasping) or occur in cyclical movements (e.g., walking, rowing), there is usually a high degree of temporal congruence between actual and imagined performance. But when the skill being performed involves complex, attention-demanding movements (e.g., golf putting, tennis serving), people tend to *over-estimate* imagined duration. In order to identify the cognitive mechanisms mediating the relationship between imagined and actual skilled performance, it may be helpful to use eye-tracking technology as an objective method for investigating online cognitive processing during "eyes open" motor imagery. By comparing the eye-movements of people engaged in mental and physical practice, we may be able to investigate the attentional processes activated by imaginary action (see Heremans, Helsen, & Feys, 2008).

Before concluding this section, a potentially important gap in research on imagery in athletes may be identified. Specifically, although a wealth of evidence has been gathered on imagery use in athletes (e.g., see Weinberg, 2008), imagery researchers in sport have largely neglected *meta-imagery* processes or athletes' knowledge of, and control over, their *own* mental imagery skills and experiences (Moran, 2002). Recently, MacIntyre and Moran (2007a, 2007b) explored meta-imagery processes in elite athletes. An interesting discovery from these studies was that athletes sometimes deliberately generated *negative* imagery content based on the belief that it would help them to cope with possible future adversity. This intentional use of negative imagery may reflect an intuitive attempt at symbolic threat desensitization. It is different from the involuntary imaginary experience of negative 'flashbacks' that sometimes occurs when athletes try to overcome past setbacks (e.g., recovery from injury; Evans, Hare, & Mullen, 2006).

New directions for cognitive sport psychology

In this paper, I have argued that cognitive sport psychology has contributed significantly to theoretical understanding of mental processes (e.g., expertise, attention, mental imagery) that are central to research in cognitive psychology and cognitive neuroscience. I have also indicated how cognitive neuroscientists' understanding and measurement of motor imagery could be improved by greater collaboration with imagery researchers in cognitive sport psychology. Such collaboration would be helpful in boosting the influence and citation frequency of cognitive sport psychology in the cognitive sciences. In order to increase the prominence of cognitive sport psychology in cognitive psychology and cognitive neuroscience, however, at least three issues need to be considered.

First, given the limitations of the traditional information processing approach to the mind, cognitive sport psychology researchers should consider alternative theoretical perspectives postulated in cognitive psychology and cognitive neuroscience (e.g., grounded cognition; Barsalou, 2008). In this regard, Beilock's (2008) review of the relevance of the *embodied cognition* paradigm for sport psychology is timely and thought-provoking. Second, research on cognitive processes in athletes is likely to be most influential in the cognitive sciences if it can seek to uncover relevant theoretical mechanisms. In pursuit of this latter objective, eye-tracking technology can provide a window on the dynamics and possible mechanisms underlying "real time" cognitive processing. Similarly, non-invasive functional neuroimaging techniques such as transcranial magnetic stimulation may be valuable in identifying the neural substrates of cognitive processes in skilled performers. A great deal of caution is warranted here, however, as Dietrich (2008) and Milton, Small, and Solodkin (2008) have recently outlined a number of theoretical and methodological barriers to the valid use of neuroimaging techniques with athletes. Clearly, we should be wary of the speculative, atheoretical use of neuroimaging as a "fishing expedition". As Cacioppo, Berntson, and Nusbaum (2008) warned, "neuroimaging is an important new tool in the toolbox of psychological science, but one that is most productive scientifically when its use is guided by psychological theories and complemented by converging methodolgies" (p. 67). Finally, the advent of motor cognition as a field of inquiry highlights the increasing importance of inter-disciplinary collaboration between researchers in cognitive sport psychology, cognitive psychology and cognitive neuroscience.

References

Abernethy, B., Maxwell, J. P., Jackson, R. C., & Masters, R. S. W. (2007). Skill in sport. In F. T. Durso (Ed.), *Handbook of applied cognition* (2nd ed.). (pp. 333–359) Chichester, West Sussex: John Wiley.

Adams, J. A. (1987). Historical review and appraisal of research on the learning, retention and transfer of human motor skills. *Psychological Bulletin, 101*, 41–74.

Aglioti, S. M., Cesari, P., Romani, M., & Urgesi, C. (2008). Action anticipation and motor resonance in elite basketball players. *Nature Neuroscience, 11*, 1109–1116.

Bar-Eli, M., & Raab, M. (2006). Judgment and decision making in sport and exercise: rediscovery and new visions. *Psychology of Sport and Exercise, 7*, 519–524.

Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology, 59*, 617–645.

Bartlett, F. C. (1932). *Remembering: a study in experimental and social psychology*. Cambridge: Cambridge University Press.

Bartlett, F. C. (1947). The measurement of human skill. *British Medical Journal, 14 June*, 835–838.

Beilock, S. L. (2008). Beyond the playing field: sport psychology meets embodied cognition. *International Review of Sport and Exercise Psychology, 1*, 19–30.

Cacioppo, J. T., Berntson, G. G., & Nusbaum, H. C. (2008). Neuroimaging as a new tool in the toolbox of psychological science. *Current Directions in Psychological Science, 17*, 62–67.

Calmels, C., Holmes, P., Lopez, E., & Naman, V. (2006). Chronometric comparsion of actual and imaged complex movement patterns. *Journal of Motor Behavior, 38*, 339–348.

Callow, N., & Hardy, L. (2004). The relationship between the use of kinasethetic imagery and different visual imagery perspectives. *Journal of Sports Sciences, 22*, 167–177.

Calvo-Merino, B., Glaser, D. E., Grèzes, J., Passingham, R. E., & Haggard, P. (2005). Action observation and acquired motor skills: an fMRI study with expert dancers. *Cerebral Cortex, 15*, 1243–1249.

Campbell, M., & Moran, A. P. (2005). Measuring the perceptual abilities of golfers to judge slope in a virtual 3 dimensional environment. 11th Congrès International de l'ACAPS, 26–28 Octobre 2005, Paris. In N. Benguigui, P. Fontayne, M. Desbordes, & B. Bardy (Eds.), *Recherches actuelles en sciences du sport* (pp. 347–348). Paris: EDP Sciences.

Claxton, G. (1980). Cognitive psychology: a suitable case for what sort of treatment? In G. Claxton (Ed.), *Cognitive psychology: New directions* (pp. 1–25) London: Routledge.

Cross, E. S., Hamilton, A. F. de C., & Grafton, S. T. (2006). Building a motor simulation de novo: observation of dance by dancers. *NeuroImage, 31*, 1257–1267.

Cumming, J., & Ramsey, R. (2009). Imagery interventions in sport. In S. D. Mellalieu, & S. Hanton (Eds.), *Advances in applied sport psychology: a review* (pp. 5–36). Abingdon, Oxford: Routledge.

Decety, J. (1996). Do imagined and executed actions share the same neural substrate? *Cognitive Brain Research, 3*, 87–93.

Dietrich, A. (2008). Imaging the imagination: the trouble with motor imagery. *Methods, 45*, 319–324.

Driskell, J., Copper, C., & Moran, A. (1994). Does mental practice enhance performance? A meta-analysis. *Journal of Applied Psychology, 79*, 481–492.

Eccles, D. W. (2006). Thinking outside of the box: the role of environmental adaptation in the acquisition of skilled and expert performance. *Journal of Sports Sciences, 24*, 1103–1114.

Eccles, D. W. (2008). Experts' circumvention of processing limitations: an example from the sport of orienteering. *Military Psychology, 20*, S103–S121.

Ericsson, K. A. (2005). Recent advances in expertise research: a commentary on the contributions to the special issue. *Applied Cognitive Psychology, 19*, 233–241.

Ericsson, K. A., & Smith, J. (1991). Prospects and limits in the empirical study of study of expertise: an introduction. In K. A. Ericsson, & J. Smith (Eds.), *Toward a general theory of expertise: Prospects and limits* (pp. 1–38). Cambridge: Cambridge University Press.

Ericsson, K. A., & Ward, P. (2007). Capturing the naturally occurring superior performance of experts in the laboratory. *Current Directions in Psychological Science, 16*, 346–350.

Ericsson, K. A., & Williams, A. M. (2007). Capturing naturally occurring superior performance in the laboratory: translational research on expert performance. *Journal of Experimental Psychology: Applied, 13*, 115–123.

Ericsson, K. A., Charness, N., Feltovich, P. J., & Hoffman, R. R. (Eds.). (2006). *The Cambridge handbook of expertise and expert performance*. New York: Cambridge University Press.

Evans, L., Hare, R., & Mullen, R. (2006). Imagery use during rehabilitation from injury. *Journal of Imagery Research in Sport and Physical Activity, 1*, 1–21.

Eysenck, M. W., & Calvo, M. G. (1992). Anxiety and performance: the processing efficiency theory. *Cognition and Emotion, 6*, 409–434.

Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: attentional control theory. *Emotion, 7*, 336–353.

Farah, M. J. (1984). The neurological basis of mental imagery: a componential analysis. *Cognition, 18*, 245–272.

Finke, R. A. (1979). The functional equivalence of mental images and errors of movement. *Cognitive Psychology, 11*, 235–264.

Fourkas, A., Bonavolontà, V., Avenanti, A., & Aglioti, S. (2008). Kinesthetic imagery and tool-specific modulation of corticospinal representations in expert tennis players. *Cerebral Cortex, 18*, 2382–2390.

Goldstein, E. B. (2008). *Cognitive psychology* (2nd ed.). Belmont, CA: Thomson.

Gueugneau, N., Crognier, L., & Papaxanthis, C. (2008). The influence of eye movements on the temporal features of executed and imagined arm movements. *Brain Research, 1187*, 95–102.

Guillot, A., & Collet, C. (2005). Duration of mentally simulated movement: a review. *Journal of Motor Behavior, 37*, 10–20.

Hardy, L., & Callow, N. (1999). Efficacy of external and internal visual imagery perspectives for the enhancement of performance on tasks in which form is important. *Journal of Sport & Exercise Psychology, 21*, 95–112.

Hardy, L., Jones, G., & Gould, D. (1996). *Understanding psychological preparation for sport: Theory and practice of elite performers*. Chichester, West Sussex: John Wiley.

Heremans, E., Helsen, W. F., & Feys, P. (2008). The eyes as a mirror of our thoughts: quantification of motor imagery of goal-directed movements through eye movement registration. *Behavioural and Brain Research, 187*, 351–360.

Herrmann, D. J., Yoder, C. Y., Gruneberg, M., & Payne, D. G. (2006). *Applied cognitive psychology: a textbook*. London: Routledge.

Hodges, N. J., Starkes, J. L., & MacMahon, C. (2006). Expert performance in sport: a cognitive perspective. In K. A. Ericsson, N. Charness, P. J. Feltovich, & R. R. Hoffman (Eds.), *The Cambridge handbook of expertise and expert performance* (pp. 471–488). Cambridge: Cambridge University Press.

Isaacson, M. (2008). Emmons loses gold on last shot again. 18 August. Available at. *Los Angeles Times*. http://articles.latimes.com/2008/aug/18/sports/sp-olyshoot1. Accessed 17.01.09.

Jackson, P. L., & Decety, J. (2004). Motor cognition: a new paradigm to study self-other interactions. *Current Opinion in Neurobiology, 14*, 259–263.

Jeannerod, M. (1994). The representing brain: neural correlates of motor intention and imagery. *Behavioural and Brain Sciences, 17*, 187–245.

Jeannerod, M. (1997). *The cognitive neuroscience of action*. Oxford: Blackwell.

Jeannerod, M. (2001). Neural simulation of action: a unifying mechanism for motor cognition. *NeuroImage, 14*, 103–109.

Johnson, P. (1982). The functional equivalence of imagery and movement. *The Quarterly Journal of Experimental Psychology, Section A, 34*, 349–365.

Katinka, D., MacMahon, C., & Mine, M. (2008). The effects of golf expertise and presentation modality on memory for golf and everyday items. *Acta Psychologica, 128*, 298–303.

Kosslyn, S. M. (1994). *Image and brain: the resolution of the imagery debate*. Cambridge, MA: MIT Press.

Kosslyn, S. M., Ganis, G., & Thompson, W. L. (2001). Neural foundations of imagery. *Nature Reviews: Neuroscience, 2*, 635–642.

Kremer, J., & Moran, A. (2008). *Pure sport: Practical sport psychology*. London: Routledge.

MacIntyre, T., & Moran, A. (2007a). A qualitative investigation of imagery use and meta-imagery processes among elite canoe-slalom competitors. *Journal of Imagery Research in Sport and Physical Activity, 2*(1), 1–23, article 3.

MacIntyre, T., & Moran, A. (2007b). A qualitative investigation of meta-imagery processes and imagery direction among elite athletes. *Journal of Imagery Research in Sport and Physical Activity, 2*(1), 1–20, article 4.

McAvinue, L. P., & Robertson, I. H. (2008). Measuring motor imagery ability: a review. *European Journal of Cognitive Psychology, 20*, 232–251.

Markman, K. D., Klein, W. M. P., & Suhr, J. A. (Eds.). (2009). *Handbook of imagination and mental simulation*. Hove, East Sussex: Psychology Press.

Matuszewski, E. (2008). US shooter Matt Emmons again misses gold on final shot gaffe. Sunday 17 August. Available at. *Bloomberg News*. http://www.cleveland.com/olympics/index.ssf/2008/08/us_shooter_matt_emmons_againm.html. Accessed 17.01.2009.

Memmert, D., & Furley, P. (2007). "I spy with my little eye!": breadth of attention, inattentional blindness, and tactical decision making in team sports. *Journal of Sport & Exercise Psychology, 29*, 365–381.

Milton, J., Solodkin, A., Hlustik, P., & Small, S. L. (2007). The mind of expert motor performance is cool and focused. *NeuroImage, 35*, 804–813.

Milton, J., Small, S. L., & Solodkin, A. (2008). Imaging motor imagery: methodological issues related to expertise. *Methods, 45*, 336–341.

Moran, A. P. (1996). *The psychology of concentration in sport performers: a cognitive analysis*. Hove, East Sussex: Psychology Press.

Moran, A. (2002). In the mind's eye. *The Psychologist, 15*, 414–415.

Moran, A. P. (2009). Attention in sport. In S. Mellalieu, & S. Hanton (Eds.), *Advances in applied sport psychology: a review* (pp. 195–220). London: Routledge.

Moran, A. P., & MacIntyre, T. (1998). 'There's more to an image than meets the eye': a qualitative study of kinaesthetic imagery among elite canoe-slalomists. *The Irish Journal of Psychology, 19*, 406–423.

Moran, A., and MacIntyre, T. (2008). Motor cognition and mental imagery: new directions. Paper presented at Conference on functional, algorithmic and implementational aspects of motor control and learning. 16 May, Liverpool Hope University.

Morris, T., Spittle, M., & Watt, A. P. (2005). *Imagery in sport*. Champaign, IL: Human Kinetics.

Müller, S., Abernethy, B., & Farrow, D. (2006). How do world-class cricket batsmen anticipate a bowler's intention? *The Quarterly Journal of Experimental Psychology, 59*, 2162–2186.

Munzert, J., Lorey, B., & Zentgraf, K. (in press). Cognitive motor processes: the role of motor imagery in the study of motor representations. Brain Research Reviews, Doi: 10.1016/j.brainresrev.2008.12.024.

Olsson, C. J., Jonsson, B., & Nyberg, L. (2008). Internal imagery training in active high jumpers. *Scandinavian Journal of Psychology, 49*, 133–140.

Olsson, C. J., Jonsson, B., Larsson, A., & Nyberg, L. (2008). Motor representations and practice affect brain systems underlying imagery: an fMRI study of internal imagery in novices and active high jumpers. *The Open Neuroimaging Journal, 2*, 5–13.

Pashler, H. (1999). *The psychology of attention*. Cambridge, MA: MIT Press.

Posner, M. I., & Rothbart, M. K. (2007). Research on attention networks as a model for the integration of psychological science. *Annual Review of Psychology, 58*, 1–23.

Roland, P. E., & Friberg, L. (1985). Localization of cortical areas activated by thinking. *Journal of Neurophysiology, 53*, 1219–1243.

Ross, P. E. (2006). The expert mind. *Scientific American, 295*, 64–71.

Ross, R., Callow, N., Hardy, L., Markland, D., & Bringer, J. (2008). Movement imagery ability: development and assessment of a revised version of the vividness of movement imagery questionnaire. *Journal of Sport & Exercise Psychology, 30*, 200–221.

Smith, E. E., & Kosslyn, S. M. (2007). *Cognitive psychology: Mind and brain*. Upper Saddle River, NJ: Pearson.

Tenenbaum, G., & Eklund, R. C. (Eds.). (2007). *Handbook of sport psychology* (3rd ed.). New York: John Wiley.

Vaeyens, R., Lenoir, M., Williams, A. M., Mazyn, L., & Philippaerts, R. M. (2007). The effects of task constraints on visual search behaviour and decision-making skill in youth soccer. *Journal of Sport & Exercise Psychology, 29*, 156–175.

Vickers, J. N., & Williams, A. M. (2007). Performing under pressure: the effects of physiological arousal, cognitive anxiety, and gaze control in biathlon. *Journal of Motor Behavior, 5*, 381–394.

Ward, J. (2006). *The student's guide to cognitive neuroscience*. Hove, East Sussex: Psychology Press.

Wegner, D. M. (1994). Ironic processes of mental control. *Psychological Review, 101*, 34–52.

Weinberg, R. S. (2008). Does imagery work? Effects on performance and mental skills. *Journal of Imagery Research in Sport and Physical Activity, 3*, 1–21, article 1.

Williams, A. M., & Ericsson, K. A. (2005). Perceptual-cognitive expertise in sport: some considerations when applying the expert performance approach. *Human Movement Science, 24*, 283–307.

Williams, A. M., & Ericsson, K. A. (2008). From the guest editors: how do experts learn? *Journal of Sport & Exercise Psychology, 30*, 653–662.

Williams, A. M., & Ford, P. R. (2008). Expertise and expert performance in sport. *International Review of Sport & Exercise Psychology, 1*, 4–18.

Wilson, M. (2008). From processing efficiency to attentional control: a mechanistic account of the anxiety-performance relationship. *International Review of Sport and Exercise Psychology, 1*, 184–201.

Wilson, M., Smith, N. C., Chattington, M., Ford, M., & Marple-Horvat, D. E. (2006). The role of effort in moderating the anxiety-performance relationship: testing the prediction of processing efficiency theory in simulated rally-driving. *Journal of Sports Sciences, 24*, 1223–1233.

Witt, J. K., & Proffitt, D. R. (2008). Action-specific influences on distance perception: a role for motor simulation. *Journal of Experimental Psychology: Human Perception and Performance, 34*, 1479–1492.

Wright, M. J., & Jackson, R. C. (2007). Brain regions concerned with perceptual skills in tennis: an fMRI study. *International Journal of Psychophysiology, 63*, 214–220.