Working Memory, Attentional Control, and Expertise in Sports: A Review of Current Literature and Directions for Future Research

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The aim of the present review was to investigate the theoretical framework of working memory as it relates to the control of attention in sport and thereby apply cognitive psychological theory to sports, but also use the sports domain to advance cognitive theory. We first introduce dual-process theories as an overarching framework for attention-related research in sports. Then a central mechanism is highlighted how working memory is involved in the control of attention in sports by reviewing research demonstrating that the activated contents in working memory control the focus of attention. The second part of the paper reviews literature showing that working memory capacity is an important individual difference variable that is predictive of controlling attention in a goal-directed manner and avoiding distraction and interference in sports. Finally, we address the question whether differences in working memory capacity contribute to sport expertise.

Keywords: Dual-process, Working memory, Attention, Sport, Individual differences

Until fairly recently great athletes were typically described in terms of physical ability so researchers did not pay much attention to cognitive factors involved in sport performance (Starkes, Helsen, & Jack, 2001). On a colloquial level dichotomies like jocks vs. nerds or brain vs. brawn might have kept researchers from studying cognition in sport performance as the physical aspect of sports has far more intuitive appeal than the cognitive aspect. In addition, when looking back at the historical development of psychological research, the experimental information processing approach to cognition forced psychologists to break down large problems and questions about the functioning of the human mind into very small and isolated aspects of cognition (see Mandler, 2007 for a review). As a consequence, each area of research became increasingly specialized to answer ever more specific questions and in turn lost sight of how the individual cognitive components interact in everyday behavior (Styles, 2005). Neisser (1976, p. 7) recognized this problem and stressed that, despite the difficulty of studying cognition, psychologists have to make "a greater effort to understand cognition as it occurs in the ordinary environment and in the context of natural purposeful activity".

In the field of memory research, a major advance in this regard was made by Baddeley and Hitch (1974, p. 47) with their concept of working memory: "despite more than a decade of intensive research on the topic of short-term memory, we still know virtually nothing about its role in normal human information processing". Today the concept of working memory is one of the most researched topics currently in cognitive psychology. Working Memory can be defined as the cognitive mechanisms capable of retaining a small amount of information in an active state for use in ongoing tasks (for reviews, see Baddeley, 2007; Conway, Jarrold, Kane, Miyake, & Towse, 2007; Cowan, 1995; Miyake & Shah, 1999). Hence, working memory is of central importance to understanding human cognition as it occurs in everyday life and scholars have attributed an important evolutionary advantage to species possessing the capacities of working memory (Carruthers, 2013; Engle, 2010). The most important advance of the working memory model was the proposal of a system not only responsible for the storage of information but also for mechanisms of cognitive control and attention (Baddeley & Hitch, 1974; Baddeley, 2003) which made the model applicable to complex behavior.

In the present article we build on the progress that has been made in cognitive psychology by reviewing research on the special cognitive component working memory, especially as it relates to attentional control, to enhance understanding of sport performance. We not only attempt to apply cognitive theory to the sports domain, but also use the sports domain to advance cognitive psychological theory (Moran, 2009; Moran & Brady, 2010). By adopting dual-process theories (Evans & Stanovich, 2013a, 2013b; Furley, Schweizer, & Bertrams, 2015; Kahneman, 2011; Schneider & Shiffrin, 1977) as a meta-theoretical starting

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point, the first section of this paper highlights the close relationship of working memory and attention and argues that this relationship can be considered a central cognitive mechanism in the control of attention in sports (Furley & Memmert, 2013). In the second part of the paper we use individual differences in working memory capacity and sport expertise to shed further light on attentional control in sport and follow the call of Cronbach (1957) who argued that the richness of human behavior can only be fully understood by combining experimental and differential approaches to psychology.

Dual-Process Theories and Sports Performance

Numerous theories propose that human behavior is controlled by two qualitatively different modes of processing, automatic and controlled processing (Frankish & Evans, 2009; see Furley et al., 2015 for a more detailed account of dual-process theories in sport). These two forms of processing are specified by their reliance on attentional control which can be defined as the goal-directed allocation of cognitive processing resources to internal and external stimuli (Pashler, Johnston, & Ruthruff, 2001).

An influential dual-process model that attempts to establish commonalities of various domain specific dual-process theories is the default-interventionist model (Evans & Stanovich, 2013a). This model distinguishes between *Type 1* processing—defined as both initiated and completed in the presence of relevant triggering conditions—and Type 2 processing—defined as requiring working memory for hypothetical thinking and mental simulation (Evans & Stanovich, 2013a). Importantly, *Type 1* processes are distinguished from *Type 2* processes by the assumption that the response/solution to a problem has become part of its cognitive representation. For example when solving a simple equation like 2 + 2 or when an experienced track-and-field athlete crosses hurdles during a race. In both cases the solution to the problems is triggered by the context without requiring further controlled processing as it is part of the cognitive representation of that problem. Similarly, certain stimulus configurations on the sport field can automatically trigger a certain response of an athlete, for example if a point-guard in basketball perceives that his defender is too far away from him and therefore takes the open jump shot. The solution has become part of the cognitive representation because of the great amount of practice and learning experiences of experienced athletes.

On the other hand, *Type 2* processes are required either to override a triggered response that is part of a representation or for a response to a novel problem that has never become part of a representation. It is important to note that *Type 2* processes can also be triggered by the context, but only *Type 1* processes autonomously run to completion as the response is part of the cognitive representation. *Type 2* processes might be initiated autonomously but subsequently require working memory engagement to be completed (Thompson, 2013). Further, Thompson (2013) argues that working memory engagement is not an all or nothing criterion, but can vary depending on the task demands. Therefore, *Type 2* processes should be defined along a continuum regarding their demands on working memory.

Successful sport performance often requires *Type 1* processing as time pressure does not allow for the effortful controlled *Type 2* processing. On the contrary, Type 2 processing has the potential to disturb athletic performance as predicted by the *paralysis by analysis* hypothesis (e.g. Baumeister, 1984; Beilock & Carr, 2001; Hardy, Mullen, & Jones, 1996; Masters, 1992)—i.e. skilled performance can be disrupted from directing attention toward monitoring the skill execution. A large amount of practice and training in sports is undertaken precisely to circumvent the limitations of the slow effortful *Type 2* processing and automate behaviors (e.g. Schmidt & Wrisberg, 2004; Williams & Ericsson, 2005) as the cognitive demands during skill execution decrease with continuous practice (e.g. Anderson, 1982; Fitts & Posner, 1967; Schmidt, 1975; Schneider & Shiffrin, 1977). Therefore, highly practiced basketball players do not need to attend to dribbling the ball and instead can use their freed attentional resources for higher order processes (e.g. scanning for open teammates).

Given the importance of autonomous *Type 1* processing in sports it is not surprising that the study of human motor performance has mainly been driven by a "neo-Gibsonian approach with little regard for the relevance of internal representations such as schemata, or cognitive concepts such as Shallice's SAS" (Baddeley (2007, p. 317)). Similarly, Toner and Moran (2014, p. 1) concluded that contemporary theorizing in sports overemphasizes the autonomous nature of skilled sport performance: "instead of relying wholly on unthinking spontaneity to guide their performance, elite athletes appear to alternate between different modes of cognitive processing".

For this reason, the present review focuses on the involvement of Type 2 processing's "centerpiece" working memory in controlling attention in sports.

Controlling Attention in Sports

Attention can be defined as subsuming all cognitive processes responsible for increasing or decreasing the level of activation of internal or external representations (Desimone & Duncan, 1995; Knudsen, 2007; Pashler et al., 2001; Posner & Petersen, 1990). According to Pashler et al. (2001) attention increases or decreases the level of activation according to both the goals and needs people have and the stimuli that impinge on them. Pertinent to the present review, recent evidence demonstrates a reciprocal relationship between the current contents of working memory and attention. This shows that attention does not only allow stimuli to access working memory (e.g. Atkinson & Shiffrin, 1968) but working memory can also influence the control of attention (Soto & Humphreys, 2007, 2008) by modulating the sensitivity of neural circuits in favor of the information currently being processed in working memory (Gazzaley & Nobre, 2012; Knudsen, 2007).

A theory of attentional control that takes both bottom-up sensory factors and top-down working memory factors into account is the *biased competition theory* (BCT, Desimone & Duncan, 1995) of selective attention. Objects in the world and internal representations compete for processing resources, and this competition is biased toward information that is currently relevant

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