WORKING MEMORY AND THE CONTROL OF ATTENTION IN SPORT: FROM GENERAL MECHANISMS TO INDIVIDUAL DIFFERENCES

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Affidavit following the section 6, paragraph 2, No. 5 and 10 of the doctorate rules from the German Sports University Cologne, from September 29th, 2004.

Hereby I declare: The work presented in this thesis is the original work of the author except where acknowledged in the text. This material has not been submitted or in part for a degree at this or any other institution. Those parts or single sentences, which have been taken verbatim from other sources, are identified as citations. I further declare that I complied with the actual “guidelines of qualified scientific work” of the German Sport University Cologne.

Philip Furley
Abstract

The major aim of the present research programme was to investigate the theoretical framework of working memory as it relates to the control of attention in sport because attention research in sport has been criticized for lacking a suitable theoretical framework (Bocher, 2008). Chapter 2 introduces the concept of working memory in combination with dual-process theories of cognitive control (Kahneman, 2011) and establishes how these two bodies of literature can be combined to form a guiding theory for attention research in sport. In Chapter 3 a central mechanism is highlighted how working memory is involved in the control of attention in sport. Seven experiments demonstrate that the activated contents—visual objects and verbal instructions—in working memory control the focus of attention in sport decision making situations. Chapter IV 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. Two experiments demonstrate that athletes with a high working memory capacity are more successful at staying focused, avoiding distraction, and impulsive errors in specific sport situations. Chapter V discusses whether differences in working memory capacity as they related to the control of attention contribute to sport expertise. The conducted studies do not indicate that working memory capacity contributes to sport expertise as high level athletes did not differ to both low level athletes and non-athletes on this basic capacity. Chapter VI specifies how the research program has broadened and extended the sports attention and expertise literature, having both theoretical and practical implications, and offering some promising avenues for future investigations.
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Chapter 1

Introduction
Beside the multifaceted challenges the Olympic athletes were confronted with in their respective sports during London’s 2012 Olympic Games, England’s capital posed an additional “challenge” not only to the athletes but also to the millions of visiting spectators from all over the world. At first sight the “challenge” I am referring to has nothing to do with sports but is suitable for introducing the overarching theme of this cumulative thesis. The “challenge” I have in mind is caused by the fact that people in Great Britain drive on the left side of the road instead of the right side as in most other nations. This not only makes driving in London for people from right-hand traffic countries a real challenge compared to the effortless habit of driving in their home country but also the simple everyday routine of crossing the road suddenly becomes a problem that requires careful attention.

People who grew up in right-hand traffic countries have become accustomed to first orient their gaze and attention to the left before they cross the road because this is where the important information of approaching cars is expected. In the course of time this looking behavior becomes automated and therefore requires less and less controlled attention. In this manner people become well “equipped” for crossing the road in right-hand traffic countries as they adapt to the constraints imposed upon them in their home environments. Unfortunately, these people are less well “equipped” to cross the road when visiting London for the 2012 Olympics and therefore special instructions were installed at road crossings telling people to first look to the right to override their automatic tendency of orienting their attention to the left.

The conducted studies outlined in this synopsis are not about crossing the road and this anecdotal example does not have anything to do with Olympic sports or
sports in general but it is highly suitable to introduce the main topic that the studies reviewed in this synopsis have in common: the control of attention in sports.

**Aims of the Thesis**

Although researchers have acknowledged the importance of attention in sport (Abernethy, 2001; Memmert, 2009; Moran, 1996; Wulf, 2007) research in this area is underdeveloped and has been conducted in a piecemeal fashion without a suitable overarching theoretical framework: “a suitable framework to study the influence of attention on sport skills has not been established” (Boucher, 2008, p. 326). This paradigm-specific research has recently been criticized (Meiser, 2011) as providing only limited insight into the function of attention in everyday behavior (Kingston, Smilek, Ristic, Friesen, & Eastwood, 2003).

In the present thesis I attempt to address this shortcoming by building on recent progress in cognitive psychology suggesting that the theoretical framework of Working Memory (WM, Baddeley & Hitch, 1974) is highly useful for studying attention in complex everyday behavior (Baddeley, 2007, Conway, Jarrold, Kane, Miyake, & Towse, 2007, Cowan, 2005, Miyake & Shah, 1999) such as sport. By adopting dual-process theories (Kahneman, 2011; Schneider & Shiffrin, 1977) as a theoretical starting point I attempt to highlight a general mechanism of how WM controls attention before I systematically investigate individual difference variables to further illuminate the relationship of WM and attentional control in sport and specifically in the development of sport expertise.
Chapter 2

Theoretical Framework and Outline of the Synopsis
Dual Process Theories as a Theoretical Starting Point

On a very general level numerous psychological theories agree that human behavior is controlled by two qualitatively different modes of processing, automatic and controlled processing (Schneider & Shiffrin, 1977): dual-process theories of social cognition (Smith & DeCoester, 2000), person perception (e.g. Gilbert, 1989; Zárate, Sanders, & Garza, 2000), judgment & reasoning (De Neys, 2006), attention (Barrett, Tugade, & Engle, 2004; Scheider & Shiffrin, 1977), mental control (e.g., Wenzlaff & Wegner, 2000), self-regulation (Baumeister & Heatherton, 1996), and emotion (Teasdale, 1999). These theories share the idea that the two forms of cognitive processing are characterized specifically by their reliance on attentional control. Controlled attention or attentional control refers to the cognitive processes that focus attention in a goal-directed manner and resolve response competition and conflict in interference situations (Engle & Kane, 2004). In such cases psychologists also speak of “executive control” or “executive attention” (e.g., Baddeley & Logie, 1999; Engle, 2002; Norman & Shallice, 1986; Posner & DiGirolamo, 2000) to emphasize family resemblance to more general theories of executive functioning. As the term controlled attention is more concrete and understandable I will use this term in the following text.

Recently progress has been made in establishing the commonalities of the various domain specific dual-process theories (e.g. Kahneman, 2011). For the purpose of the present thesis I will borrow Kahneman’s (2011) distinction of System 1 and System 2. System 1 is believed to operate automatically and quickly with hardly any effort as it does not depend upon controlled attention, whereas System 2 is responsible for (effortful) mental activities that require controlled attention. According to Kahneman (2011, p. 24) both Systems are active whenever we are
awake: “System 1 runs automatically and System 2 is normally in a comfortable low-effort mode, in which only a fraction of its capacity is engaged”.

As one may imagine, successful sport performance most often requires System 1 as the many constraints (Davids, Button, Bennett, 2007) of successful sports performance such as extreme time pressure do not allow for the effortful slow activity of System 2. For example, Olympic champions like Michael Phelps or Usain Bolt do not need a whole lot of effortful thinking when elegantly racing through London’s 2012 Aquatic Centre or Olympic stadium. Similarly, Germany’s gymnastics star Fabian Hambüchen does not have to strain his attention on the successful execution of his silver medal winning horizontal bar routine—on the contrary this might even disturb smooth execution as predicted by the \textit{paralysis by analysis} hypothesis (e.g. Baumeister, 1984; Beilock & Carr, 2001; Hardy, Mullen, & Jones, 1996; Masters, 1992). US American Olympic “Dream Team” superstar Kobe Bryant also does not need to pay attention to skillfully dribbling the ball but instead can use his free attentional resources to find LeBron James underneath the “hoop” who then scores with a spectacular dunk.

All these examples primarily highlight the involvement of the effortless System 1 and for this reason it is not surprising that a great deal of training in sports is undertaken precisely to circumvent the limitations of the slow effortful System 2 and automate behaviors (e.g. Williams & Ericsson, 2005). In plenty of situations in sports System 1 will get the job done smoothly and efficiently but in some situations System 2 is required just as in the everyday example of a person from a right-hand traffic country crossing the road during the 2012 London Olympic Games. In such situations, when the situation demands a different behavior to that which one has become accustomed to, System 2 is required to deliberately control attention in
adapting behavior appropriately—i.e. to resolve response competition and conflict in interference situations. A sport example illustrative of resolving response competition is if a soccer defender anticipates that Bayern Munich’s right wing player Arien Robben always feints to the outside to then cut to the center and therefore positions himself accordingly. In this case Robben will need System 2 to adapt his behavior to the demands of the situation and not rely on his habitual behavior of cutting to the center.

People also need System 2 to carry out intentions or action plans—i.e. focus attention in a goal directed manner. Kahneman (2011, p. 36) points out that probably the most important capability of System 2 is “the adoption of “task sets” [that] can program memory to obey an instruction that overrides habitual responses.” These task sets—e.g. instructions or self-generated intentions—are stored or activated in a special memory system called working memory (WM, Kahneman, 2011) which is a crucial cognitive system for controlling attention (e.g Engle, 2002) as will be demonstrated throughout this synopsis.

**Outline of Publications included in the Synopsis**

The synopsis of this cumulative dissertation outlines the eight peer-reviewed manuscripts in table 1 that investigate the involvement of System 2’s “centerpiece” working memory in controlling attention in sports and how this might contribute to expert performance in sports. The first part of the synopsis will illuminate a general mechanism of how WM controls attention in sports before I systematically investigate how individual differences in WM relate to attentional control and superior performance in sports (Vogel & Awh, 2008).
Table 1

Publications Included in Synopsis


Before describing the conducted studies, the relevant theoretical constructs and perspectives drawn upon in this thesis are introduced, which are reviewed in more detail in *Publication I*. In this first section I go on to highlight the close relationship of WM and attention from a cognitive information processing perspective and argue that this relationship can be considered a central cognitive mechanism in the control of attention. In *Publications II and III* I investigate how WM can control attention in sports and discuss what implications this might have for sport specific decision making. In the second part of the synopsis I use individual
difference in WM capacity and sport expertise to shed light on the importance of attentional control in sport. In this respect *Publication IV* tests whether a greater capacity of WM might be beneficial in some situations in sports as this greater capacity affords superior attentional control. If this were the case then it might be beneficial for athletes to have a greater WM capacity—either via a selection process or because they cognitively adapt to the specific constraints imposed upon them. This is discussed in *Publications II, III, V, VI, VII, VIII* and unpublished data. I end the synopsis by discussing the combined implications from the results obtained in the studies on attentional control in sports both from a theoretical and applied perspective.
Research questions addressed in the thesis. Specifically this thesis addresses three main research questions outlined in table 2.

Table 2


<table>
<thead>
<tr>
<th>Research Question</th>
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<tbody>
<tr>
<td>I. How is attention controlled in sports and what role does WM play in this process?</td>
<td>3 Experiments in Publications II</td>
</tr>
<tr>
<td>a. What effects can instructions have on attentional control in sports?</td>
<td>4 Experiments in Publications III</td>
</tr>
<tr>
<td>II. When is controlled attention needed in sports and do athletes benefit in situations requiring controlled attention from having a greater WM capacity?</td>
<td>2 Experiments in Publication IV</td>
</tr>
<tr>
<td>III. Do athletes differ in their basic information processing capacity—specifically their attentional control capacity—compared to non athletes in a way which might contribute to sport expertise?</td>
<td>3 Experiments in Publication V, VI, and 1 unpublished Experiment</td>
</tr>
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Theoretical Background and Relevant Constructs\(^1\)

Although I introduced dual-process theories in the introduction as a theoretical starting point, in the broadest possible sense the conducted studies are embedded in the information processing framework following the seminal work of Broadbent (1958) and Neisser (1967, 1976). For many years the study of the working of the mind, including memory and attention, was considered impossible and unscientific. It was not until the middle of the 20\(^{th}\) century that psychologist started to experimentally study internal concepts, such as attention and memory, that lay

\(^1\) See Appendix I for more detail.
between stimulus and response. This 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. Therefore cognitive psychologists were forced to concentrate on individual cognitive components, such as memory or attention, in isolation because it was highly difficult to experiment on multiple components at the same time. 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”.

Similarly Broadbent (1971, p. 4) emphasizes his insistence that psychological theory has to be grounded in real-life experience:

The researcher remote from immediate practical pressures may indeed be free to study major variables in which at this instant society does not seem to be interested; but he should not use this freedom in order to study minor variables, until there are no major ones within reach of our techniques. The necessity for some relevance to real life is a worthwhile intellectual discipline.

If research on cognitive processes loses touch with real life contexts then laboratory studies may generate fundamental misunderstanding of human cognition and behavior (Kingston et al., 2003). Therefore, laboratory studies have to attempt to generalize from general laboratory paradigms to paradigms that are more representative of real world-situations (Kingston et al., 2003).
For example, 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 WM, who, just like Neisser (1976), acknowledged that studying cognitive concepts such as memory in isolation is problematic if the aim is to understand everyday behavior: “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”. Since then further advances have been made that demonstrate the close interaction of cognitive concepts such as memory, attention, and perception that were formally studied in isolation (for a review see Styles, 2005).

In the present synopsis I build on the progress that has been made in cognitive psychology by studying the interplay of the special cognitive component WM and attention to enhance understanding of the “natural purposeful activity” of sport performance. In this respect, I attempt to usefully apply cognitive psychological theory to inform knowledge of performance in the sports domain and (ii) further use the sports domain to advance cognitive psychological theory. Moran (2009) and Moran and Brady (2010) argue that the field of sports offers a fruitful domain to explore the validity of models developed in other fields. Further, it has been suggested that in some instances the field of sports offers a “rich and dynamic natural laboratory” to advance cognitive psychological theory (Moran, 2009, p. 420). In this endeavor it is inevitable to first briefly describe the cognitive components in question and their hypothesized function and relationship.

**Working Memory.** Alan Baddeley (2012, p. 2) emphasizes that the concept of WM is one of the most researched topics currently in cognitive psychology by stating that “the topic of working memory has increased dramatically in citation counts since the early years, […] a recent attempt to review it (Baddeley 2007) ended...
with more than 50 pages of references”. It has even been described in an amusing verse by Janice Keenan in Miyake and Shah’s book *Models of Working Memory* (1999, p. XVIII) which is well suited to both illustrate the main features (cf. figure 1) of this cognitive concept in a memorable way and further highlight the overwhelming amount of attention WM has received.

> “There once was a box called short-term store
> Whose function was storage and nothing more.
> But along came Alan Baddeley
> Whose subjects dual-tasked madly
> And WM replaced STS forever more.
>
> For those who’ve been living in caves
> Working memory is a system with slaves.
> They are independent buffers
> So neither one suffers
> When doing verbal memory and visual maze.
>
> While storage is the job of each little slave
> The central executive says how we behave
> It activates and controls all nodes
> Through a dopamine system acting as gates.
>
> The unanswered questions on WM abound
> Despite numerous studies whose findings are sound.
> What’s needed right now
> Is for us to see how
> We can put all these data on common ground.”

*Figure 1, left column.* Baddeley’s revised model of WM incorporating links with long-term memory (Baddeley, 2002, p. 93). *Right column.* Janice Keenan’s Ode to WM.

As described in Janice Keenan’s verse, WM can be defined as the cognitive mechanisms capable of retaining a small amount of information in an active state for use in ongoing tasks and it therefore seems hard to think of situations in which WM is not required. Therefore, researchers (for reviews, see Baddeley, 2007, Conway et al., 2007, Cowan, 2005, Miyake & Shah, 1999), have recognized the importance of WM in numerous laboratory and everyday situations. The most important advance of the WM 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) which made the model applicable to complex behavior. The model comprises an attentional control system, the central executive, and three subsidiary storage systems, the phonological loop, responsible for holding speech-based or acoustic information, the visuospatial sketchpad, holding visual and spatial information, and the episodic buffer holding episodic amodal information (cf. figure 1). For the purpose of this synopsis I mostly neglect the storage components of WM and focus on the processing aspect: the central executive (Baddeley & Hitch, 1974, Baddeley, 2003; Engle, 2002).

Baddeley (2003) claims that the central executive is the most important, but least understood, component of WM. The first attempt to advance the concept came with the proposal (Baddeley, 1986) to adopt Norman and Shallice’s (1986) model of attentional control as the central executive. This model overlaps to a considerable extent with the aforementioned dual-process theories and closes the gap between WM and dual-process theories as both share the central tenet that behavior is controlled at two levels. The first is fairly automatic and based on habits and schemas (comparable to Kahneman’s System 1), whereby cues in the environment trigger the appropriate behavior—e.g., driving on one’s daily route to work. The other level is a mechanism for overriding such habits and was termed the Supervisory Attentional System (SAS, which is comparable to Kahneman’s System 2). The SAS is utilized when habit patterns are no longer adequate and attention has to be deployed in a goal-directed manner—e.g., if there are roadworks on one’s daily route to work and one is forced to take appropriate action to circumvent the obstruction (Shallice, 1988; Shallice & Burgess, 1991).
Attention. Humans have a limited information-processing capacity (for a review, see Broadbent, 1958; for a recent review, see Knudsen, 2007), and given the enormous amount of information that bombards people, it becomes essential for performance efficiency that the most task-relevant (or pertinent) information gets processed. Hence, our attentional system has evolved to limit processing to objects that are currently relevant for our behavior in a given situation as our sensory system cannot process all the available information (e.g. Broadbent, 1958; Neisser, 1967; Treisman, 1969; Allport, Styles, & Hsieh, 1994). In the present synopsis, I adopt a very general definition of attention as mechanisms to increase or decrease the level of activation of internal or external representations (e.g. Pashler, Johnston, & Ruthruff, 2001).

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. In this respect, attention can be regarded as lying on a continuum reflecting the relative influence of these two factors in their causation; internal representations—referred to as top-down processes—and external stimuli—referred to as bottom-up processes. There is a large body of evidence showing that stimulus-driven factors such as sudden onsets of new stimuli (Yantis & Jonides, 1990; Yantis & Hillstrom, 1994) or salient stimuli (Lee, Itti, Koch, & Braun, 1999; Theeuwes 1992; Braun 1999) capture or guide attention in a fairly automatic way. However, since humans are usually involved in some task or are striving to achieve some kind of goal, an entirely bottom-up dominated attentional system would be of little use. Therefore, people need some kind of mechanism for directing attention in a top-down manner. Recent research demonstrated that this top-down directing of attention is likely to be controlled by the information held in WM at that time (e.g. Soto,
Hodsoll, Rotshtein, & Humphreys, 2008 for a recent review). This proposed connection between WM and attention provides the starting point of the completed series of studies in this synopsis.

**Interaction of WM and attention.** Scientists used to think of the relationship between attention and memory as operating only in one direction. Attention was conceptualized as a filter that selects only relevant information for access into the short-term processing stores (e.g. Atkinson & Schiffrin, 1968). Recent evidence demonstrates that there is a reciprocal relationship between the current contents of WM and attention. Hence, attention does not only allow access into WM but WM can also influence the guidance of attention (Awh, Jonides, & Reuter-Lorenz, 1998; Downing, 2000; Huang & Pashler, 2007; Soto, Heinke, Humphreys, & Blanco, 2005; Soto & Humphreys, 2007, 2008) by modulating the sensitivity of neural circuits in favour of the information currently being processed in WM (Gazzaley & Nobre, 2012; Knudsen, 2007).

Soto et al. (2008) argue that one reason for assuming a close link between attention and WM is that both seem to draw on a common pool of resources as indicated by a series of studies of Lavie (2005). For this reason, numerous researchers propose in large-scale theories of cognition that WM representations control the allocation of attention to objects that match features of the WM representations or are related to them (e.g., Anderson, Matessa, & Lebiere, 1997; Logan & Gordon, 2001). Of course, the properties of the external stimuli also play a role in determining the allocation of attention, as discussed before. An influential theory of attentional control that takes both bottom-up sensory factors and top-down WM factors into account is the *biased competition theory* (Desimone & Duncan, 1995) of selective attention.
The biased competition theory of selective attention (BCT). Visual objects in the world compete for cognitive representation, analysis, and control at some point between stimulus input and response, and this information is biased towards information that is currently relevant for behavior (Desimone & Duncan, 1995). Thus, in a nutshell, the theory proposes that attention serves to enhance the response of behaviorally relevant neurons and that the effect of attention on neuronal responses is best understood as competition between competing stimuli and representations. For example, stronger sensory inputs usually have an advantage over weaker sensory stimuli, but the content of WM can bias the competition, tipping the balance towards the weaker stimuli. Hence, if a visual object is preactivated in WM and later appears in the visual display, this object will have an advantage in the competition for selective attention. The winner of this competition then becomes the focus of attention.

More specifically the BCT proposes that objects that are present in a visual scene activate corresponding representations in the brain, which compete for both perceptual awareness and motor behavior. According to the BCT, top-down control is influenced by an internal template activated in the circuitry of WM, priming an object in the visual scene to the disadvantage of competing objects in the visual scene. It is suggested that these internal templates arise from WM (Chelazzi, Miller, Duncan, & Desimone, 1993; Desimone and Duncan, 1995; Reynolds, Pasternak, & Desimone, 2000) and in turn bias neural activity that encode particular features of an object in the visual scene that become the focus of attention.

Based on BCT I first conducted a series of studies addressing research question I: How is attention controlled in sports and what role does WM play in this process?
Chapter 3

General Mechanisms: Attentional Control by WM in Sports
Sport offers researchers an ideal setting to test BCT and follow the call of Kingston et al. (2003) to test attentional paradigms in a representative real world context because sports typically involve time pressured dynamic situations in which athletes have to employ attention efficiently in order to select one out of several decision options, e.g. which team-member to pass to. According to BCT, stronger sensory inputs usually have an advantage over weaker sensory stimuli, but the content of WM can bias the competition, tipping the balance towards the weaker stimuli. This assumption can be transferred to the context of sports as illustrated in the following example: a basketball point guard might not pass to a team-member under the “hoop” who is waving (stronger stimulus) but instead passes to the shooting guard at the three point line because of the intended offensive play announced by the coach during the last timeout, in which he was told that the team needs open 3-point shots in order to win the game. In this scenario the point guard is probably holding a representation of the player he is attempting to pass the ball to in his or her WM and according to BCT this representation is likely to bias attention towards that player and in turn increase the chances of passing the ball to this player. If this player is unmarked, then the activated template of that player will facilitate the decision to pass to him according to BCT. On the other hand, if the player is guarded by an opposing player, attention will still be allocated towards that player and will have to be reallocated towards an open team-member, which will consume valuable milliseconds of the limited time available in a fast moving sport.

A further reason why team sports offers an ideal testing ground for BCT is the fact that there are usually numerous objects such as team-member passing opportunities and opponents competing for attention and action. Most of these visual objects are behaviorally relevant and compete for limited attentional resources.
Hence, if there are multiple competing objects in a complex time constrained sport scene then the top-down bias from WM might have a greater influence on attentional guidance as there is more competition to be resolved in very short time.

**Main Findings on Attentional Control from WM in Sports**

In three experiments participants (experienced athletes and novices) had to hold an image of a certain player in WM—which was controlled by a memory probe task—while engaged in a time constrained decision task.

In Experiment 1 participants had to identify as quickly as possible which player—out of either 2 or 4 players—was in possession of the ball by pressing a corresponding key on the keyboard. The results support BCT by demonstrating that attention was controlled by a template held in WM. Response times were significantly faster when the object activated in the circuitry of WM matched (valid) the target object in the quick decision task—i.e. was the same as the player in possession of the ball—compared to when the player held in WM was not present among the available choices (neutral) or was present but was not in possession of the ball (invalid). Besides demonstrating attentional guidance from WM on the response time data the results from Experiment 1 further showed that the contents of WM also influence the number of impulsive decision errors. Therefore, the results demonstrate that there can be both benefits and costs from the attentional control from WM in sports.

Interestingly, the attention guidance effect from WM was especially pronounced in complex situations in which more players were present in the visual array that could potentially be the target (ball holder). By increasing the number of potential “ball-holders” in the experimental task participants were required to

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2 See Appendix II for full detail.
broaden their attentional window (Hernández, Costa, & Humphreys, 2010) which in turn increased attention guidance effects by WM as more objects were competing for attention.

In Experiment 2 participants had to decide which player to pass to in a schematic team handball situation. The results demonstrated that if a team-sport athlete forms the intention to pass to a certain player—which we argue involves holding a representation of that player in WM—then his or her attention will be automatically directed towards this player and thereby facilitates the decision to pass to this player. In situations in which this player is unmarked this attentional guidance effect from WM is beneficial (valid trials), whereas it is detrimental in situations in which the player is guarded as attention is drawn to this player automatically and subsequently has to be reoriented towards a more suitable recipient of the pass. This pattern of results was evident both in the response time data and in the error rate data. Hence, holding a representation of a certain player in WM does not only influence attentional orientation but also the actual decision of whom to pass to. Again, as the complexity of the decision making situation increased (caused by more passing options), decision makers were affected to a greater extent by attentional control from WM as participants more often passed to a marked player who matched an activated representation in WM.

The purpose of Experiment 3 was to make the experimental stimuli more representative of the visual demands athletes are confronted with during sporting performance. Therefore, we replaced the cartoon images from Experiment 1 and 2 by photographs of a basketball court and basketball players. In order to strengthen our argument that BCT is a helpful theory to explain how an athlete’s attention is controlled during decision making we followed the call of Kingston et al. (2003) of
increasing the external validity of the task. This point is further stressed by Fiedler (2011; see also Simmons, Nelson, & Simonsohn, 2011) who pointed out the necessity of replicating effects found in one set of stimuli with different stimuli to ensure that the phenomenon of interest—in this case attentional guidance from WM in sport decision making—does not only apply to a certain set of stimuli or experimental paradigm but has general applicability regarding the behavior or phenomenon of interest. The results from Experiment 3 scrutinize the findings from Experiment 1 and 2 while increasing the external validity of the attentional guidance effect from WM in team-sport decision making. Hence, an athlete’s attention is guided towards certain team-members who resemble internal templates that are currently being held in WM.

Answer to Research Question I: “How is attention controlled in sports and what role does WM play in this process”. The results from three experiments clearly show that the current contents of WM control an athlete’s focus of attention. Decision options receive a competitive advantage if they are associated with the activated contents in the circuitry of WM. This effect is especially pronounced in complex decision making situations with several decision options competing for attention. Based on these findings I suggest that the link between WM and attention can be considered a central mechanism in “everyday purposeful activities” (Neisser, 1976) via its function to program top down attentional control.

Hence, the results from Publication II provide evidence for Kahneman’s (2011) claim that an important function of System 2 is the adoption of “task sets” by programming memory to control attention. A useful analogy to clarify this mechanism is a thermostat (Folk, Remington, & Wright, 1994). A thermostat is set to a specified temperature and then activates the heating system automatically when the
temperature diverges from the pre-set temperature without requiring any further intervention from the person who set the thermostat. Thus, the person controls the thermostat, but the control is executed “off-line”. Folk et al. (1994) claim that the same is true for attention, by stating that templates currently active in the circuitry of WM—such as team-member passing opportunities or higher level cognitive goals—determine attentional control settings in advance and that external stimuli that match the internal representations to some degree will capture attention without any further cognitive involvement.

I elaborate on such theorizing in the next section by addressing research question 1a whether certain instructions e.g. given by the coach can have a similar effect on attentional guidance as visual objects held in WM.

The Effects of Instructions on Attentional Control in Sports

In the previous section I showed that the contents of WM control attention in favor of certain information at the cost of different information. In this context, Williams, Davids, and Williams (1999) mentioned that “the coach should help performers to develop ‘mind-sets’ or expectations regarding which cues to attend to and which ones to ignore” (p. 54, see also Hageman & Memmert, 2006). In the next series of studies we investigated how coaches of team ball sports might be able to utilize instructions in this endeavor by guiding an athlete’s focus of attention to what are considered information-rich areas.

In 4 experiments we investigated whether attention-guiding instructions can potentially induce an attentional set (Most, Scholl, Clifford, & Simons, 2005) or task set (Kahneman, 2011), directing the attentional focus of the players. To test this assumption we conducted a series of experiments embedded within the Inattentional

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3 See Appendix III for full detail.
Blindness paradigm (Mack & Rock, 1998; Most et al., 2005; Simons & Chabris, 1999) which has close connections to the attentional WM literature (Fougnie & Marois, 2007; Todd, Fougnie, & Marois, 2005; De Fockert & Bremner, 2011). In a typical inattentional blindness paradigm a specific attentional set or task set is induced that controls the focus of attention of the participants while at some point an unexpected event occurs that is not part of the task set. For example in the most prominent inattentional blindness paradigm (Simons & Chabris, 1999) participants were asked to count how many times a group of players wearing white shirts passed a ball, while ignoring passes by another group of players wearing black shirts. This activated a task set in WM that enhanced the attention paid to white representations and decreased the activation of black representations to the extent that participants even missed a man in a black gorilla costume walking through the visual display.

In this regard, we tested whether tactical instructions can have a similar negative effect on tactical decision making in sports by inducing a task set that guides attention away from important information (Furley, Memmert, & Heller, 2010, Appendix III). Of relevance in this respect, Moores, Laiti, and Chelazzi (2003; see also Duncan & Humphreys, 1989) review evidence that top-down control signals from WM representations do not only raise the activity of object representations in the visual scene that match the internal template in some properties, but this activation also spreads to associated representations. Therefore, the attentional focus is also biased towards objects that are merely associated with the current templates in WM. A finding in line with this proposal is that words held in WM direct eye movements towards semantically related images (Huettig & Altmann, 2005). More recent studies (Soto & Humphreys, 2007; Huang & Pashler, 2007) corroborated these
findings by showing that verbal items that were activated in the circuitry of WM facilitated visual search of semantically related visual objects.

In our paradigm participants again had to make a tactical decision for a specific player in a five on five basketball video situation. As is common procedure in basketball training we induced an attentional set by instructing the participant that the position of their direct opponent is important for their tactical decision and that they therefore have to not only decide what they would do in the situation but further report the position of their direct opponent in this situation (as being either close to them or far away; or what the positioning of the feet was of their direct opponent). In one critical trial there was an unexpectedly free team-mate and passing to him was rated as the best tactical decision making option by basketball experts. We compared the frequency of passing to this free team-mate once with the instruction of focusing on the direct opponent and without this instruction. The results demonstrate that experienced basketball players often did not pass to the unmarked player if they received the attention-guiding instructions about the defensive player compared to when they did not receive these instructions.

All four experiments demonstrated that sport specific instructions can induce an attentional set that results in basketball players’ missing important game-relevant information. In Experiment 2, we found that players with hardly any basketball experience were more prone to this effect, as compared with experienced athletes\(^4\). The effect of attentional guidance on tactical decision making remained unchanged while improving the ecological validity of the setting by enhancing the perception–action coupling (Experiment 3) and increasing the task difficulty (Experiment 4).

\(^4\) A point I discuss in more detail when focusing on expertise related questions of attentional control in the second part of the synopsis.
Answer to Research Question Ia: “What effects can instructions have on attentional control in sports?” In Furley et al. (2010) we argue that coaches frequently give specific instructions and introduce predetermined offensive plays (e.g., American football, basketball, or handball) in order to reduce the complexity of the game and give guidance to the decision maker by directing his or her attentional focus (cf. Williams et al., 1999). These offensive strategies usually include only a subset of the players, and the decision maker therefore has to choose from only a limited number of possibilities. For this reason, it is possible that a player who is not part of a specific offensive strategy is unexpected and is not incorporated into the decision-making process. This is precisely what was modeled in this study and we were able to show that these attention guiding instructions can lead to important information being overseen.

Hence, tactical instructions can induce an attentional set by programming memory to obey these instructions (Kahneman, 2011) and thereby affecting the decision making process of athletes. In some cases tactical instructions can be beneficial (see also Furley & Memmert, 2012, Appendix IV) by reducing the complexity of the time constrained decision (Williams et al., 1999) but as the reviewed experiments point out in other situations these instructions can be detrimental for decision making by guiding attention away from important information (Furley et al., 2010). In this regard the experiments further highlight the importance of System 2 (Kahneman, 2011) in the control of attention in sport specific decision making. Based on the reviewed experiments in this section, the link between WM and attentional control can be considered a central mechanism in sport by demonstrating that information currently activated in the circuitry of WM induces a task set that controls the focus of attention.
According to Cronbach (1957), a comprehensive account of human behavior can only be achieved through the synergy of experimental and differential approaches to psychology. Hence, in the second part of the synopsis I systematically use individual differences in WM to aid further understanding of attentional control in sports performance. The conducted studies utilized a combination of experimental approaches and individual difference approaches following a recent call of Vogel and Awh (2008) who argued that cognitive theory development can substantially benefit from combining an individual-difference approach with an experimental approach. As people differ substantially in numerous respects, Vogel and Awh (2007) argue that this diversity can usefully be exploited to constrain cognitive theory, also in sport. Thus, instead of treating individual and group differences as error variance, as is common procedure in experimental approaches (Cronbach, 1957), I argue that both group and individual differences are useful in shedding further light on the importance of WM and attention in sports.
Chapter 4

Individual Differences: The Role of WM Capacity in Sports
I began this synopsis by introducing dual process theories as an overarching theoretical framework that state that behavior is determined by the interplay of automatic (System 1) and controlled processing (System 2; Kahneman, 2011) and that these two forms of processing are distinguished by their reliance on attentional control. In the first part of this synopsis I highlighted an important central mechanism of how System 2 uses WM to control attention. In the second part of the synopsis I focus on the question whether certain people are better at controlling their attention and therefore benefit in situations that require controlled attention. In this way I systematically use individual differences (Cronbach, 1957) to further investigate the involvement of System 2 in sports.

Major progress has been made in measuring a person’s ability to control attention by demonstrating that certain measures of WM capacity (WMC; Conway, Kane, Bunting, Hambrick, Wilhelm, & Engle, 2005) have been successful in predicting performance in situations affording controlled attention in the presence of interference which has led to the formulation of the controlled attention theory of WMC (see Engle, 2002 for a review). In contrast to the original notion of capacity as an amount of information (e.g., Miller, 1956), the controlled attention theory of WMC states that WMC is a domain general measure, reflecting an individual’s ability to control his/her attention (e.g., Conway et al., 2005; Kane, Bleckley, Conway, & Engle, 2001; Engle, 2002). Thus, the term WMC has been recently used to refer to “the attentional processes that allow for goal-directed behavior by maintaining relevant information in an active, easily accessible state outside of conscious focus, or to retrieve that information from inactive memory, under conditions of interference, distraction, or conflict” (Kane, Conway, Hambrick, & Engle, 2007b, p. 23). A large body of research has shown that people vary
considerably in their WMC (e.g., Conway et al., 2005) and that this diversity can be used to predict performance in domains that require controlled attention (Vogel & Awh, 2008).

The main tenet of the controlled attention theory of WMC is that WMC tasks predict complex cognitive behavior such as reading and language comprehension (Daneman & Carpenter, 1980; King & Just, 1991), reasoning (Kyllonen & Christal, 1990), learning and fluid intelligence (Barret et al., 2004) or even bridge playing (Clarkson-Smith & Hartley, 1990), because of the domain general controlled attention component shared by these tasks and the WMC measures. Consistent with this view, a modification of the reading span task that requires mathematical processing instead of comprehending sentences is still an excellent predictor of language comprehension because language comprehension requires controlled attention (e.g., Engle, 2002).

More direct evidence for the claim that WMC tasks measure a person’s ability to control attention has been derived from studies showing that WMC is not only predictive of high-level ability test scores and complex behavior but also of performance on low-level selective attention tasks such as the dichotic listening task (Conway, Cowan, & Bunting, 2001); the Stroop task (Kane & Engle, 2003; Long & Prat, 2002); the antisaccade task (Kane et al., 2001; Unsworth, Schrock, & Engle, 2004), and flanker tasks (Heitz & Engle, 2007). In addition, WMC does not only reliably predict attentional control in the laboratory, but further predicts people’s subjective experience of mind wandering in daily life (Kane et al., 2007a). Together these studies show that WMC tasks represent a domain free limitation in the ability to control attention that is predictive of an individual’s capability of staying focused, avoiding distraction, and impulsive errors.
Situations Requiring Controlled Attention in Sport

In the introduction I argued that a lot of skilled sports performance does not require controlled attention as it can be carried out fairly automatically with hardly any or no reliance on WM (e.g. Schneider & Shiffrin, 1977) because a great deal of training is undertaken precisely in order to circumvent the limitations of WM and automate behaviors (Furley & Memmert, 2010, Appendix I; Williams & Ericsson, 2005). The assumption that the cognitive demands decrease with continuous practice is common in the skill acquisition literature (e.g., Anderson, 1982; Fitts & Posner, 1967; Schmidt, 1975; Schneider & Shiffrin, 1977). As skill level increases, information is restructured into a different type of skill representation, which is usually referred to as a procedure (Anderson, 1982). Procedural knowledge does not require the same amount of controlled attention as declarative knowledge involved in unpracticed skill execution in which the individual components of a skill are attended to in a step-by-step fashion. For this reason, a highly practiced soccer player does not need to attend to the execution of dribbling the ball, which allows him to utilize his freed attentional resources for other aspects of the sport, such as scanning for open team-mates.

Controlled attention is not only not needed for the execution of well-learned skill execution it actually harms the smooth execution of the skill as suggested by prominent self-focus theories (Baumeister, 1984), such as the explicit monitoring hypothesis (e.g., Beilock & Carr, 2001), or the conscious processing hypothesis (Hardy, Mullen, & Jones, 1996; Masters, 1992).

In two studies (Publication IV, Appendix IV) I therefore addressed research question II: In what kind of sport situations might skilled athletes benefit from superior attentional control—besides the well-documented situations of learning new
skills (e.g. Fitts & Posner, 1967)—even if attentional control is not needed for successful skill execution in plenty of sport situations? In this regards the cognitive psychological literature (e.g., Engle, 2002) suggests that the ability to control attention is especially important during challenging activities in contexts (i) providing concurrent distraction and (ii) interference from prior experience or habit. Both of these circumstances frequently occur in competitive team sports situations: e.g. (i) team-sport athletes need to stay focused on performance while blocking out irrelevant distractions when, for example, shooting a decisive free throw in basketball while the opposing crowd is trying everything to disrupt the shooter’s concentration; (ii) athletes need to be able to quickly and efficiently select situation-appropriate actions under extreme time pressure in high-interference situations: for example, when the quarterback in American football tries to find the open receiver in the final offensive play then suddenly notices a wide “corridor” and decides for a running play instead.

Main Findings on WMC and Attentional Control in Sports

WMC in avoiding distraction in sports. In regard to focusing attention and avoiding distraction we demonstrated that basketball players scoring high on WMC measures (Conway et al., 2005) were better able to focus their attention on a computer-based basketball decision making task while blocking out irrelevant auditory distraction (Furley & Memmert, 2012, Experiment 1). Hence, WMC remained predictive of controlling attention between different modalities in this representative sport performance context, as participants were required to attend to visually presented information to decide on a sport-specific tactical decision while ignoring a stream of auditory information presented over head phones. The fact that

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5 See Appendix IV for full detail.
athletes with a high WMC reported hearing their own first name significantly less frequently in the unattended stream of auditory information shows that they were more successful in blocking out the task irrelevant auditory stream. In addition, the high WMC Basketball players appeared less prone to everyday distraction on the Cognitive Failure Questionnaire (CFQ, Broadbent, Cooper, FitzGerald, & Parkes, 1982) compared to low WMC Basketball players, which supports the suggestion that WM is important in everyday attentional control.

**WMC in Resolving Response Competition in Sports.** Athletes with a high WMC not only use their superior attentional control to focus on relevant information processing and blocking out distraction, but also use it for resolving competition between competing action tendencies and action plans (Engle, 2002 for a review). In line with the controlled attention theory of WMC, ice hockey players with a low WMC fail to adjust their tactical decisions to the demands of the game situation and more often “blindly” followed a tactical instruction they got from a virtual coach, even though it was not appropriate in the game situation (Furley & Memmert, 2012, Experiment 2). On the other hand ice hockey players with a high WMC were more proficient at adjusting their tactical decision to the demands of the situation instead of relying on the information they got during a simulated team time-out that was not appropriate for the following offensive game situation. No differences between high and low WMC ice-hockey players were evident in situations in which the tactical information they got in the team time-out was helpful for the following game situation as there was no competition to be resolved and therefore the situation did not require attentional control.
Answer to Research Question II: “When is Controlled Attention Needed in Sports and Do Athletes Benefit in Situations Requiring Controlled Attention from Having a Greater WM Capacity?”

The ability to control attention is especially important in situations providing concurrent distraction and in situations in which dominant action tendencies interfere with successful performance. Two experiments showed that WMC is predictive of successful performance in such situations due to a superior ability to control attention of high WMC athletes. The present research followed a recent suggestion in the cognitive psychology literature (Vogel & Awh, 2008) of how to “exploit diversity for scientific gain.” Accordingly, we used WMC as individual difference variable to demonstrate the involvement of the central executive component of WM in staying focused on sport-specific performance and adequately resolving response competition during tactical decision making, which are both highly important feats in team sports.

Given the importance of attentional control in team sport situations it seems feasible that this capacity might be an important factor contributing to team sport expertise. Expertise research in sport has received a great amount of research attention in the last decades. Hence, I investigated how attentional control capacities might contribute to team-sport expertise in the next chapter.
Chapter 5

Individual Differences: Team Sport Expertise, WM, and Attention
The study of how athletes reach and stay at the pinnacle of their respective sports or what factors contribute to superior performance in sport has received a great deal of attention by sport expertise researchers (Starkes & Ericsson, 2003 for a review). On a very general level expertise can be defined as the ability of a person to consistently demonstrate superior levels of performance in a specific domain over an extended time period (Starkes, 1993). Knowledge of the factors that limit and contribute to superior sport performance are important for several reasons: (i) this knowledge provides a basis for deriving types of practice and training that are most efficient for performance enhancement (Ericson, 2006); (ii) to predict who has the best chances of being successful in a particular sport (Williams & Reilley, 2000); (iii) on a theoretical level to test general theories of skill acquisition and expertise (Williams & Ericsson, 2005).

Athletes are required to adapt to specific constraints (Davids et al., 2007) imposed by the sporting environment to perform successfully or circumvent potential performance decrements. Until fairly recently great athletes were considered an “assemblage of physical prowess” so researchers did not pay much attention to cognitive factors involved in expert sport performance (Starkes, Helsen, & Jack, 2001). Today most scientists acknowledge the important role of cognitive processes in sporting performance which has led to a substantial accumulation of literature (Ericsson, Charness, Feltovich, & Hoffman, 2006; Hagemann, Tietjens, & Strauß, 2007; Starkes & Ericsson, 2003; Sternberg, & Grigorenko, 2003; Williams & Hodges, 2004) which broadly states that expert sport performers gain an advantage by acquiring cognitive skills and strategies through deliberate practice that increase their efficiency of processing information (e.g. Eccles, 2006). According to Williams et al. (1999), these adaptations are essential because the speed of many sports may
exceed the basic information-processing capacities of athletes. A topic of recent controversy within the expertise literature is the possible cognitive adaptations that occur as a function of extensive practice in sports.

A large body of evidence supports the *specific processing hypothesis*, which has recently also been named narrow transfer hypothesis (Chabris & Simons, 2010). This narrow transfer hypothesis is embedded in the theoretical framework of “Long-term Working Memory” (Ericsson & Kintsch, 1995) which in a nutshell states that expert performers bypass their natural processing limitations by acquiring special knowledge structures that function as associations between encoded information and retrieval cues in long-term memory. Hence, in order to retrieve the encoded information experts must reinstate the encoding conditions by using the same retrieval cues (Guida, Gobet, Tardieu, & Nicolas, 2012). In this manner Long-Term Working Memory becomes available for expert performers—but only in their specific field of expertise—and enables them to behave adaptively to the situational demands of their performance environment. Therefore, the narrow transfer hypothesis suggests that people with years of experience in an activity such as team sports, playing an instrument, or playing chess only differ in cognitive processing skills directly related to their field of experience and that those skills do not translate to different domains due to adaptations in “basic” cognitive abilities such as memory capacity, perceptual acuity, or intelligence (e.g., Eccles, 2006; Ericsson et al., 2006; Feltovich, Prietula, & Ericsson, 2006). For example, expert chess players do not have greater memory capacity, per se, but do have a greater memory capacity for meaningful chess configurations (Chase & Simon, 1973).

On the other hand, researchers have suggested that there might be more general cognitive enhancements from competitive sport participation: “we believe
there may be both sport specific and sport general cognitive enhancements from competitive sport training” (Voss, Kramer, Basak, Prakash, & Roberts, 2010. p. 813); “It is possible that good [soccer] players actually develop better executive functions, although these functions have been largely regarded as relatively stable through life” (Vestberg, Gustafson, Maurex, Ingvar, & Petrovic, 2012, p. 4). These statements are representative of the broad transfer hypothesis that suggests that adaptations in basic cognitive abilities occur as a result of prolonged experience in activities such as flying an airplane (Bellenkes, Wickens, & Kramer, 1997), action video-game playing (Green & Bavelier, 2003, 2006), air traffic control (Allen, McGeorge, Pearson, & Milne, 2004), or competitive sports training (Voss et al., 2010, Vestberg et al., 2012). Specifically, the broad transfer hypothesis assumes that practice in a certain activity can potentially lead to adaptations in basic cognitive abilities which in turn transfer to various different skills in more remotely related domains.

Nobody seriously doubts that athletes specifically adapt to the constraints of their respective performance environments by acquiring specific knowledge (Starkes & Ericsson, 2003; Mann, Williams, Ward, & Janelle, 2007; Williams & Ford, 2008) which is highlighted in a recent review article (Hambrick & Meinz, 2012, p. 276): “So it is clear that domain knowledge is a major source of “power” in complex tasks”. The controversial question however is whether athletes also adapt on a general cognitive ability level—e.g. have a greater WMC that affords superior attentional control—beyond these specific adaptations (Allen, Fioratou, & McGeorge, 2011; Eccles, 2006; Ericsson et al., 2006; Furley & Memmert, 2010, Appendix V; 2011, Appendix VII; Vestberg et al., 2012; Voss et al., 2010). This question (research question III) is addressed in the next section.
Attentional Control Capacities in Expert (Team Sport) Athletes

It has been suggested that success in team sports such as soccer—apart from physical skills and abilities—also depends on the general information processing capacities given the complex time-constrained environments (Vestberg et al. 2012; Voss et al., 2010). Vestberg et al. (2012, p. 1) go on to suggest that “many of the required skills in team sports may be translated to general cognitive domains where test results can be compared to a population norm. A good team player could be characterized by excellent spatial attention, divided attention, working memory, and mentalizing capacity.” Using a standardized neuropsychological assessment tool (D-KEFS; Delis, Kaplan & Kramer, 2001) to measure executive functions—i.e. WM—of high and low level soccer players, Vestberg et al. (2012) report superior executive functions of high level players compared to low level players. Further, both soccer groups scored higher on the D-KEFS compared to a standardized norm group. In addition these test scores were predictive of the goals scored and assists of the tested soccer players two years later (based on a partial correlation of the square root of the goals/assists and the test scores).

In addition, a recent meta-analysis (Voss, et al., 2010) on the sport/cognition relationship found a small-to-medium effect indicating that expert athletes performed better compared to novices on measures of processing speed and several attentional paradigms. Therefore, Voss, et al. (2010) seem to provide convincing evidence for the broad transfer hypothesis by aggregating the results of twenty studies on the sport cognition relationship in a meta-analysis.

On the other hand, we repeatedly failed to find a similar association between WM, attention, and sport expertise in our own studies. The data from Furley and

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6 See Appendix IV, V, and VI for more detail.
Memmert (2012, Appendix IV) did not indicate any differences in the central executive component of WM that is involved in the control of attention between expert athletes and standardized control populations. Given the results of Vestberg et al. (2012) it is surprising that experienced basketball players (Counting Span Score: $M = .65, SD = .07$) actually performed slightly worse compared a standardized norm population (Kane et al., 2004, Counting Span Score: $M = .69; SD = 0.15$). Expert ice-hockey players (Automized Oeration Span Score: $M = 39.82, SD = 18.3$) did not show any differences compared to a standardized norm population (Unsworth et al., 2005, Automized Oeration Span Score: $M = 39.16; SD = 17.4$). Hence, expert team sport athletes did not differ on two of the most commonly used measures on executive functioning in cognitive psychology.

The WMC measures used in Furley and Memmert (2012) have excellent psychometric properties (Conway et al., 2005) and have been validated in terms of measuring controlled attention in everyday situations (Furley & Memmert, 2012; Kane et al., 2007a) and in team sport situations (Furley & Memmert, 2012). Whereas, the measures (D-KEFS; Delis, Kaplan & Kramer, 2001) used in Vestberg et al. (2012) have only been validated as predictive of clinical disorders. In addition the D-KEFS has recently been criticized based on its psychometric properties (Baron, 2004; Schmidt, 2003).

In a further study (study in preparation for publication) I did not find any difference ($t(58) = .746, p = .46$) between high class ($M = .71; SD = .097$) and low class athletes ($M = .73; SD = .087$) across two different team sports ($N = 15$ soccer players, $N = 15$ handball players) and two individual sports ($N = 15$ track and field athletes, $N = 15$ swimmers) on WMC as measured by the counting span task (Kane et al., 2004). There was also no significant difference ($t(58) = .786, p = .44$) between
team sport ($M = .73; SD = .084$) and individual athletes ($M = .71; SD = .1$) which might have been expected based on the argumentation of Vestberg et al. (2012, p. 1) that a “good team player could be characterized by excellent spatial attention, divided attention, working memory, and mentalizing capacity.” A further well-controlled study with a large sample size did not find differences between expert team sport athletes, expert track athletes, and novices on several state of the art attention tasks (Memmert, Simons, & Grimme, 2009). A study including 112 participants also found no differences in the spatial storage component of WM between experienced basketball players and college students with no team-sport experience (Furley & Memmert, 2010, Appendix V).

Moreover, Publication II (Appendix II) highlighted the important role of WM in controlling attention but did not find any differences between a expert group and a novice group across three experiments in attentional control. In Publication VI (Appendix VI) we transferred a further attentional paradigm to sports—the perceptual load paradigm (Lavie, 2005)—that measures distractor interference and has been validated as predictive of controlled attention in everyday live (Foster & Lavie, 2007). Again, we did not find any differences between expert athletes and novices indicative of superior attentional control in the perceptual load paradigm. Given these ambiguous findings I elaborate on possible explanations that might account for some of the different results before answering research question III.

**Cognitive adaptations in the field of sport?** In this section I will first offer a potential alternative explanation for the small-to-medium effect size of enhanced processing speed and superior attentional abilities obtained in the meta-analysis (Voss et al., 2010). I then go on to discuss why some studies might find superior
executive functions of e.g. elite soccer players (Vestberg et al., 2012) in contrast to our own studies.

In Furley & Memmert (2011, Appendix VII) I argue that publication bias is an important phenomenon when attempting to draw conclusions on the relationship of sports engagement and cognitive adaptations. According to Riniolo (1997), publication bias is defined as the increased likelihood of publishing a manuscript reporting statistically significant—e.g. differences between expert and novice athletes—rather than non-significant results. Publication bias is caused by both a submission bias which occurs before the review process and a selection bias that occurs during the review process (Cooper, DeNeve, & Charlton, 1997). Evidence for this phenomenon has not only been found in psychology but also in medicine and biology (Sterling, Rosenbaum, & Weinkam, 1995; Cumming, Fidler, Leonard, Kalinowski, Christiansen, Kleinig, et al., 2007). As a result, publication bias can be responsible for an effect in the literature which actually does not exist, or for distorting the effect size in the literature (Rosenthal, 1979). Therefore, the small-to-medium effect of Voss, et al. (2010) may actually represent a much smaller effect which is distorted due to a publication bias as scientists do not write up their non-significant results due to anticipated problems during the peer review process.\footnote{See Appendix VII for more detail.}

Publication bias might be the reason for a significant effect in the meta analysis (Voss et al., 2010) but this phenomenon cannot explain why some studies find an effect of sport expertise e.g. on executive functions (e.g. Vestberg et al., 2012) whilst our studies fail to find such an effect.

A potential alternative explanation for significant effects of sport expertise on basic cognitive capacities compared to the broad transfer hypothesis might be
confounding variables associated with sport expertise. An important confounding variable that requires careful attention when studying the relationship of sport and cognition is physical fitness. Recent research (Hertzog, Kramer, Wilson, & Lindenberger, 2008; Kramer, Hahn, Cohen, Banich, McAuley, Harrison, et al., 1999) has demonstrated enhanced cognitive functioning as a consequence of increased physical fitness. Specifically, aerobic exercise has been shown to affect cognitive functioning in the prefrontal cortex which is closely related to WM and executive functioning (Hillmann, Erickson, & Kramer, 2008). While most of the literature has demonstrated the beneficial influence of aerobic fitness on executive functions in older adults (e.g. Colcombe, & Kramer, 2003; Kramer et al., 1999) there is now converging evidence linking executive control functions, such as selective attention and interference control to physical activity among children (Buck, Hillman, & Castelli, 2008; Hillman, Buck, Themanson, Pontifex, & Castelli, 2009). Thus, differences between non-athletes and athletes on cognitive tests may not have been caused by the fact that athletes cognitively adapted to the demands of the sport or by selection issues that favor superior attentional abilities, but instead simply by increased fitness of athletes compared to non-athletes. Concerning the attentional control capabilities as measured by WMC tasks I found tentative evidence (study in preparation for publication) for this assumption as hours of sport/physical activity (across a variety of sports) per week and WMC were significantly correlated ($r (n =75) = .315; p = .003$).

A further study addressing the question whether athletes excel at everyday tasks due to their sport expertise acknowledges this confounding variable by stating: “To gain insight into the role of fitness and athletics in multitasking, future research should include a high-fit age-matched group, especially given many reports that
demonstrate enhanced brain structure and function with high levels of aerobic fitness” (Chaddock, Neider, Voss, Gaspar, & Kramer, 2011, p. 1925). Besides mentioning aerobic fitness this study reveals that a further important variable to take into account is simple reaction time when studying the relation between sport expertise and cognition. Hence, differences in laboratory tests—that often involve response times—between athletes and non-athletes that propose to measure certain executive functions, such as attentional control, might be caused simply by faster reaction times of athletes and not by enhanced attentional capacities.

**Answer to Research Question III. “Do (Team Sport) Athletes Differ in Their Basic Cognitive Processing Capacity Compared to Non-athletes which might Contribute to Sport Expertise?”**

Currently data on the sport-cognition relationship are mixed and clearly more research is called for to illuminate this important topic. Based on our own findings I would answer the question with a “No”(): team sport athletes do not possess superior basic information processing capacities—e.g. a superior ability to control attention. The only evidence for expert/novice differences in my own data was apparent in Furley et al. (2010) that showed that expert basketball players more often than novices noticed an unexpected open passing option when their attention was engaged in a monitoring task that was highly specific to the sport of basketball (see Appendix III for full detail). This finding is in line with the specific processing hypothesis. Whereas I could not provide any evidence for a relationship between basic attentional capacities and sport expertise, as for example Vestberg et al. (2012) or Voss et al. (2010).

Therefore, based on the existing evidence I am not convinced that expert team sport athletes have superior attentional control capacities compared to normal,
physically active controls. I do not doubt that attentional control (i.e. WMC) is a highly important attribute in certain sport situations—as I have explicitly stated in Furley and Memmert (2012, Appendix IV)—but currently the evidence does not suggest that superior attentional control capacities significantly contribute to team sport expertise or even that WMC is a limiting factor for successful team sport performance. Attentional control capabilities seem to differ to a similar extent from athlete to athlete just as in the “general population”. Those team sport athletes that are “lucky” to have a large WMC will most likely have advantages in some sport situations that demand controlled attention as in Furley and Memmert (2012). On the other hand athletes high in WMC might do less well in other situations as I will discuss in the next chapter based on recent findings in cognitive psychology.

Given the ambiguous findings and methodological problems that do not allow a conclusive answer to research question III, I give some recommendations based on Publication VII and VIII for future research on this topic in the chapter conclusions and prospects.
Chapter 6

Conclusions and Prospects
This chapter will provide a detailed synthesis of the work presented in the thesis and outline its implications for both theory and practice. The limitations of the work are discussed, as well as potential avenues for future research on attentional control in sports.

Aims of the Thesis

The general aim of the present thesis was to examine the role of WM in controlling attention in sports from an information processing perspective (Broadbent, 1958; Neisser, 1967, 1976). By adopting dual-process theories (Kahneman, 2011; Schneider & Shiffrin, 1977) as an overarching theoretical framework I attempted to highlight a general mechanism of how WM controls attention, what sport situations require controlled attention, and whether athletes with higher attentional control capacities benefit in situations requiring controlled attention. Finally, I aimed to address the controversy in the literature whether basic abilities such as WMC contribute to sport expertise.

Summary of Key Findings

Specifically I addressed three research questions. Table 3 gives an overview of the empirical answers to these questions based on the conducted studies.
Table 3


<table>
<thead>
<tr>
<th>Research Question</th>
<th>Empirical Answer</th>
</tr>
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<tbody>
<tr>
<td><strong>I. How is attention controlled in sports and what role does WM play in this process?</strong></td>
<td>Baddeley’s model of WM comprises a central cognitive system responsible for short-term storage and an attentional control mechanism. Three experiments conclusively showed that the contents activated in the visual storage component of WM control the focus of attention. Hence, visual objects receive a competitive advantage in influencing behavior if they are congruent with the active contents in the storage components of WM in sport specific decision making.</td>
</tr>
<tr>
<td><strong>Ia. What effects can instructions have on attentional control in sports?</strong></td>
<td>In 4 experiments we demonstrated that sport-specific instructions activated in the phonological storage component of WM induce an attentional set that controls the focus of attention of athletes during decision making which—in some cases—can lead to important information being overseen.</td>
</tr>
<tr>
<td><strong>II. When is controlled attention needed in sports and do athletes benefit in situations requiring controlled attention from having a greater working memory capacity?</strong></td>
<td>In two experiments we demonstrated that the central executive component of WM is responsible for attentional control in sport situations affording concurrent distraction and in situations in which dominant action tendencies interfere with successful performance. Athletes with a greater capacity to control attention—i.e. WMC—therefore benefit in these interference situations.</td>
</tr>
<tr>
<td><strong>III. Do athletes differ in their basic information processing capacity—specifically their attentional control capacity—compared to non athletes, which might contribute to sport expertise?</strong></td>
<td>Currently ambiguous findings exist on this important topic. Our own data suggests that athletes do not possess superior basic information processing capacities—e.g. a superior ability to control attention (measured by WMC tasks) and only differ on highly sport specific processing skills.</td>
</tr>
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</table>
The findings reviewed in this thesis have important theoretical implications for theories both of attention and expertise. Further, the theoretical implications can be subdivided according to Moran (2009) in findings that (i) usefully apply cognitive psychological theory to inform knowledge of performance in the sports domain and in findings that (ii) use the sports domain to advance cognitive psychological theory. Hence, I first describe the theoretical implications of the findings for sport psychological theory—as the majority of the findings fall into this category—before I go on to highlight the ways in which some of the findings can be regarded as advancements in general psychological theory.

Implications for attentional theory in sport. In the introduction I cited Boucher (2008, p. 326) who stated that “a suitable framework to study the influence of attention on sport skills has not been established”. In this respect the results demonstrate that the WM framework (Baddeley & Hitch, 1974, Baddeley, 2003; Engle, 2002) as it relates to dual-process theories (Kahnemann, 2011; Schneider & Shiffrin, 1977) seems highly suited to addressing the shortcoming as the attentional control by the activated contents of WM seems a central mechanism that is capable of reconciling several lines of attentional research in sport psychology. Hence, it seems conceivable that the control of attention by the activated contents in WM—as demonstrated in Chapter 3—does not only apply to decision making but generalizes to a whole range of situations in sporting contexts.

For example, Attentional Control Theory (ACT, Eysenck, Derakshan, Santos, & Calvo, 2007) assumes that anxiety leads to attention shifts aimed at detecting the source of the threat causing the anxiety. In this respect anxiety-induced worries held in WM seem to direct the focus of attention toward threatening stimuli. Wilson,
Wood, and Vine (2009) found tentative evidence for such theorizing in the field of sport by demonstrating that anxious participants were more likely to focus on the ‘threatening’ goalkeeper in a football penalty kick than less anxious players.

Similarly, performance decrements due to paralysis by analysis (Baumeister, 1984; Beilock, Bertenthal, McCoy, & Carr, 2004; Gray, 2004) might also be reconciled by the WM attention relationship as it seems feasible that WM not only controls the external focus of attention but also the internal focus of attention. Baumeister (1984) suggests that pressure raises self-consciousness and worry about performing correctly. These self-conscious thoughts will be active in WM. In the attempt to avoid performance decrements attention is directed by these self-conscious thoughts to the step-by-step execution of movement (Beilock et al., 2004; Gray, 2004). Paradoxically, this has exactly the opposite effect to that intended. Instead of avoiding performance decrements by directing attention to skillful execution, various studies (e.g. Baumeister, 1984; Beilock et al., 2004; Gray, 2004) found evidence that this explicit attention disrupts well learned skills, because System 2 (Kahneman, 2011) is too slow to deal with the real time control of the proceduralized skills.

In addition, the fact that individual differences in WMC predicted performance in situations requiring controlled attention in sports as reviewed in Chapter 4 not only demonstrates that controlled attention is needed to successfully perform in specific sport situations but also highlights the cognitive mechanism responsible for controlled attention—the central executive component of WM (Baddeley & Hitch, 1974). Hence, the central executive component of WM proved to be responsible for staying focused on sport-specific performance and adequately
CONCLUSIONS AND PROSPECTS

resolving response competition during tactical decision making, which are both highly important feats in team sports.

**Implications for general attentional theory.** Recently Kingston and colleagues (2003, p. 177) stated that “our research suggests that laboratory studies conceived and interpreted in isolation from real-world experience may do far worse than fail to generalize back to the natural environment; they may generate fundamental misunderstanding of the principles of human attention”. Hence, the most important implication of the conducted studies for general theories of attention is that—contrary to the findings reviewed in Kingston et al. (2003) on attentional orienting—WM remained predictive of controlled attention in experimental settings representative of sport decision making. Therefore, WM theory can be considered a helpful theoretical framework for studying attention in the real world and explaining complex human behavior.

In addition, and in agreement with Moran’s (2009, p. 420) claim that sports can offer a “rich and dynamic natural laboratory” to advance cognitive psychological theory, I wish to highlight several findings in which the conducted studies advanced current understanding in cognitive psychology.

First, in *Publication II* we extended previous work on the biased competition theory of attention by demonstrating that attentional guidance effects were not only evident in the response times but also in errors in the decision task, which suggests that once the focus of attention has been guided towards a memory matching object this object also receives a competitive advantage in influencing behavior—i.e. in the context of sports, passing to a certain player even if this player is guarded by an opponent player.
Further, and of particular theoretical interest, the attentional control effect from WM increased in tandem with the complexity of the situation. An increase in complexity of the decision making situation in sport requires athletes to adopt a broader attentional focus which results in greater attentional guidance effects as there is more information competing for limited attentional capacity. Therefore the contents of WM had a greater effect on resolving the competition between the objects in the visual scene and choosing a passing option. Desimone and Duncan (1995) suggest that objects in the world compete for cognitive representation, analysis, and control sometime between stimulus input and response and that this competition is biased towards information that is currently relevant for behavior. As humans have a limited information processing capacity, the currently activated contents of WM bias attention in order to resolve the competition in favor of the behaviorally most relevant visual objects. Following this argumentation it seems logical that stronger attentional guidance effects from WM should emerge the more objects compete to influence behavior, as was the case in Publication II.

As a further novel contribution to the cognitive psychological literature, evidence in Publication IV demonstrated that WMC remains predictive of controlling attention between different modalities in a sport performance context, as participants were required to attend to visually presented information to decide on a sport-specific tactical decision while ignoring a stream of auditory distraction. This finding is of theoretical interest because it directly contrasts with modality specific views of attention (Duncan, Martens, & Ward, 1997; Schneider & Detweiler, 1988; Soto-Faraco, Morein-Zamir, & Kingstone, 2005) which argue that attentional capacity and temporary storage are peculiar to each modality and representations in one modality should therefore not interfere with representations in another.
Implications for expertise theory in sport and in general. A major topic of interest in both psychology and sport science is how people achieve high levels of skills in such areas as sports, music, or other games (see Hambrick & Meinz, 2011 for a recent review). This topic is deeply embedded in the long-standing nature versus nurture debate (e.g. Ridley, 2003) that concerns the relative influence of innate factors versus learning and experience in determining e.g. skill level or expertise. Sir Francis Galton (1869, p. 38) expressed an extreme form of the nature view upon discovering that eminence runs in families: “if the ‘eminent’ men of any period, had been changelings when babies, a very fair proportion of those who survived and retained their health up to fifty years of age, would, notwithstanding their altered circumstances, have equally risen to eminence”. On the other hand, John Watson (1930/1970, p. 2012) proposed the opposing nurture view in its extreme form: “practicing more intensively than others, is probably the most reasonable explanation we have today not only for success in any line, but even for genius”.

Today, the extreme versions of the nature and nurture views have become less popular and most researchers acknowledge the importance of both acquired characteristics and basic abilities (Hambrick & Meinz, 2011). However, it is not clear what basic abilities might contribute to expertise in different domains. For example, sport expertise research has been greatly influenced by research on expertise in the field of chess (Chase & Simon, 1973; de Groot, 1965) which arguably has quite different requirements from e.g. team sports. Conclusive evidence exists in both domains that acquired domain specific knowledge contributes to superior performance in both sports (for a review, see Starkes et al., 2001; William et al., 1999) and chess (Chase & Simon, 1973; de Groot, 1965). It has been suggested that this acquired domain specific knowledge serves to circumvent performance
limitations (Ericsson, Krampe, & Tesch-Römer, 1993) associated with basic abilities, e.g. WMC: “Performers can acquire skills that circumvent basic limits on working memory capacity” (Ericsson & Charness, 1994, p. 725).

In a series of studies Hambrick and Meinz (2011) challenged the circumvention of limits hypothesis (Ericsson et al., 1993) by demonstrating that WMC is associated with superior performance in complex tasks even in expert individuals with high levels of domain-specific knowledge. Hence, Hambrick and Meinz (2011, p. 278) conclude that “available evidence does not justify the claim that basic abilities are always unimportant for skilled performance: There is now good evidence that basic abilities predict success in a wide range of complex tasks, from chess to music, even among highly skilled performers”.

However, the studies in team sport on WMC reviewed in this thesis do not warrant suggesting that WMC is an important limiting basic ability in every performance domain. Clearly, the requirements of sports are quite different to those of playing chess, the piano, or texas holdem poker and therefore different abilities are likely to be important in different domains. Therefore, general theories of expertise have to take the specific constraints of the performance situations into account and pay careful attention not to over-generalize the implications of specific findings in one domain across all domains as the relative influence of basic abilities and domain specific knowledge is bound to vary across domains. In the field of sport, research on this important topic has just begun and has revealed ambiguous findings. Thus, more research is warranted to illuminate the role of basic abilities such as WMC in superior sports performance as discussed in the section on limitations and future research directions.
Practical Implications of the Findings

The studies reviewed have important applied implications. Especially the findings on attentional control in the Chapters 3 and 4 provide a useful theoretical framework for deriving practical interventions in sports. In addition I discuss the practical implications of the individual differences findings of WMC and sport expertise.

Controlling the attentional focus. *Publications II and III* demonstrated that the current contents of WM—visual objects or verbal instructions—control the focus of attention of athletes by inducing an attentional set. This finding in sports has far-reaching practical implications as it suggests that athletes can “load” their WM voluntarily with certain information in order to control their attentional focus. Similarly coaches can “load” the WM of athletes and thereby influence their attentional focus in a desired manner.

The experiments showed that attentional guidance from WM can have both beneficial and detrimental effects on tactical decision making. On the positive side the findings from *Publication II* show that information held in WM can facilitate tactical decision making if it fits the situation—for example if the information in WM guides attention towards a certain team-member who is subsequently open and therefore passing to him or her would be a sound tactical decision. On the other hand our results show that this attentional guidance effect can also have detrimental consequences on tactical decision making by directing the attentional focus away from important information which can lead to a slow-down in finding a suitable tactical solution, as attention has to be redirected. Not only can this effect slow down tactical decision making but it can also lead to important information being overseen and therefore results in suboptimal decisions. As this effect is particularly
pronounced in complex situations team-sport athletes have to be highly careful in forming intentions of passing to a certain player as the defense might anticipate a pass to this player and there will not be enough time to reorient attention. Instead, athletes have to decide appropriately to the situation and not rely on preformed intentions, especially in complex situations that include several decision opportunities.

A direct consequence of this finding is that coaches have to be careful about giving tactical instructions or announcing “too many” specific offensive plays as it can make the decision maker literally blind to more appropriate tactical decisions that are not part of the instruction or offensive play (Furley et al., 2010, Appendix III, Memmert & Furley, 2007). In many team sports, it is considered state-of-the-art to practice precise predetermined offensive plays, especially in American football, basketball, handball, and so forth. These offensive routines guide the visual attention of the decision maker (e.g., the quarterback). The decision maker has to focus only on selected aspects of a specific constellation, because every player has received precise instructions on how to behave. Since the decision maker focuses his attention accordingly, (s)he has only limited options, often in the form of if–then rules, to choose from. Our findings indicate that this method is not always beneficial and athletes would often benefit from fewer instructions, leading to more creative behavior, which, in turn, would make the athlete less predictable for the opponent. Especially when training tactical decision making, it is beneficial to induce a broad breadth of attention by giving fewer instructions and not rigidly practicing offensive routines (Memmert, 2007).

Beside the straightforward implications of the attentional control findings from WM in Publications II and III the results seem to have even further reaching
practical implications. With reference to dual-process theories (Kahneman, 2011) I argued that various situations in sport only require System 1 that operates largely without controlled attention and that well-learned skill execution is harmed by reinvesting attentional control (Baumeister, 1984; Beilock et al., 2004; Gray, 2004). Hence, “loading WM” with information that directs attention away from monitoring skill execution should have beneficial consequences for executing a well-learned skill.

Such theorizing shows substantial overlap with the pioneering work of Timothy Gallway (e.g. 1974/1997) on coaching and the development of personal and professional excellence in sport and other fields. Similar to Kahneman (2011) Gallway (1974/1997) distinguishes \textit{self 1} and \textit{self 2}, with \textit{self 1} being responsible for controlled processing and \textit{self 2} for automatic processing\textsuperscript{8}. Gallway (1974/1997) argues in his popular “Inner Game” publications that one has to let \textit{self 2} perform the actions in sports such as Tennis or Golf in order to be successful, without \textit{self 1} interfering by evaluating every action. Gallway goes on to suggest that \textit{self 1} gives the instruction to \textit{self 2}, which performs the action, and gives concrete examples of how \textit{self 1} can help \textit{self 2} to perform the action instead of interfering. For example when performing a tennis shot \textit{self 1} can give the instruction to watch the rotation of the seam on the tennis ball in order to achieve the desired goal of focusing attention on the tennis ball and thereby avoiding unwanted conscious monitoring of the shot, as research has shown that this kind of external focus of attention is beneficial (Wulf, 2007 for a review) for smooth skill execution. The attentional guidance findings by WM perfectly serve as a theoretical background for deriving these kind of practical applications proposed by Gallway (1997).

\textsuperscript{8} Exactly opposite to Kahneman’s distinction of System 1 being automatic and System 2 controlled.
In addition, one might argue that the momentary contents of WM cannot only control an athlete’s attentional focus, but that e.g. imagery—a function of the visual-spatial sketchpad (figure 1) of Baddeley and Hitch’s (1974) model—could have a kind of training effect on a person’s attentional focus by training an athlete’s attentional focus towards task-relevant cues during performance and away from irrelevant cues. This argumentation is not new and was first stated by Feltz and Landers (1983), who claimed that imagery could facilitate the development of a beneficial attentional set during sport performance.

Another area within sport psychology that might benefit from the WM attention link is psychological skill training. Some of the positive effects of self-talk strategies, visuo-motor behavior rehearsal, mental practice or goal-setting strategies might be attributable to loading WM with beneficial information which in turn helps control an athlete’s attentional focus. Therefore, future research should elaborate on the WM attention link as it is a promising field for future research in this area.

**Can athletes benefit from WMC training?** Based on the individual difference findings on WMC and sport expertise I will briefly discuss whether athletes might benefit from training their WMC in order to improve their attentional control capabilities as advertised by several companies (e.g. [http://www.cogmed.com/executives-and-athletes](http://www.cogmed.com/executives-and-athletes); retrieved on 30.08.2012). In view of several lines of evidence I would currently not recommend athletes, coaches, or sport teams to invest training time and other valuable resources in computer-based WMC training.

First, the studies reviewed in Chapter 5 do not suggest that WMC is a limiting factor for successful sport performance and so far studies have only suggested that
WM training can be an effective intervention for individuals for whom WMC is a limiting factor in everyday life (Klingberg, 2010, for a review).

Second, presently the evidence for cognitive enhancements through computerized WM training is at best mixed, with some studies reporting cognitive improvements after computer-based WMC training (Klingberg, 2010) and others not (e.g., Owen et al., 2010). Anyway, the more important question concerning the present research is not whether performance on cognitive tests can be improved by training but whether WM training can improve performance in sports. To date, the evidence does not support the notion that training programs advertised to improve WMC and in turn everyday attentional control among healthy adults improve cognitive functioning beyond the tasks that are actually being trained (Owen et al., 2010). Similarly, previous endeavors to improve athlete’s performance via generalized visual training programs have not proven to be successful (e.g., Abernethy & Wood, 2001). Therefore, in consideration of the present evidence on WMC training, coaches would probably be better advised to conduct sport-specific training to enhance decision making instead of incorporating computer-based WM training sessions into their training schedules.

Limitations and Directions for Future Research

Despite the novel contribution of the findings on WM and attentional control in sports the conducted studies are not without their limitations. First, as most of the studies were computer based laboratory studies that modelled sport decision making, it is not clear whether the findings generalized directly to real world sports performance. In both Publication II and III we successively made the experimental tasks more representative of sport decision making without the pattern of results changing significantly, which is indicative that the results are not a result of the
experimental paradigms chosen but generalize to the behavior in question. In this respect, we followed a recent call by Meiser (2011; Fiedler, 2011; Simmons, Nelson, & Simonsohn, 2011) to increase the external validity of the task, who pointed out the necessity of replicating effects found with one set of stimuli with different stimuli to ensure that the phenomenon in question applies not only to a certain stimulus set but actually generalizes towards the behavior or phenomenon at issue. Nevertheless, future research should continue this approach and investigate whether the attentional guidance effect is evident in situ on the playing field.

Similarly, the findings from Publication IV linking WMC to controlled attention in sport at this stage do not warrant the conclusion that good decision makers—such as quarterbacks in American football or point guards in basketball—necessarily need to be high on WMC. Even though the current study demonstrated that athletes with a high WMC were more successful in focusing their attention and resolving response competition in a decision-making task related to their field of expertise, it is currently unclear whether this translates to successful decision making on the respective sport fields (see Dicks, Button, & Davids, 2010). Therefore, before making too “hasty” applied recommendations, it is important to follow up these first results in even more representative sport scenarios. In this respect, a combination of individual difference approaches concerning WMC with both in situ experimental work (Dicks et al., 2010) and field research seem a fruitful avenue for future research to scrutinize whether WMC remains predictive of controlled attention in actual sporting competition. Only when WMC has proven to be predictive of controlled attention in sport competitions might coaches and managers wish to consider using WMC measures, for example, for screening, intervention, or even selection purposes.
In addition, although WMC was beneficial in specific situations representative of sport performance, the capacity of superior attentional control might be less beneficial or even detrimental in other sport situations, as research from cognitive psychology suggests. For example research indicates that people with a high WMC suffer more from performance pressure as they are used to relying on this capacity. Under pressure performance worries block the use of WM on which high capacity individuals usually rely and in turn their performance suffers in comparison to people with a lower WMC (Ashcraft, & Kirk, 2001; Beilock, 2008). Further, it seems feasible that athletes with a greater WMC might over-analyze skill execution which leads to paralysis by analysis (Baumeister, 1984; Beilock & Carr, 2001; Masters, 1992) as spare attentional capacity “spills over” to the conscious monitoring of skill execution with the intention of circumventing potential performance decrements. DeCaro and Beilock (2010) also suggested that learning and skill execution might be more associative in nature and less dependent on controlled effort for low WMC people. A further aspect of sport performance that might suffer from too much attentional control might be creative performance which has proven to be an important aspect of team sports (Memmert, 2011). At present, ambiguous findings exist on the relationship of WMC and creativity in the cognitive literature. While some studies suggest that WMC benefits creative behavior (DeDreu, Nijstad, Baas, Wolsink, & Roskes, 2012), others suggest that WMC harms creative problem solving by focusing too narrowly (Wiley & Jarosz, 2012). Taken together, all these suggestions can be empirically tested with the approach highlighted in Publication IV and future research should address these important questions to advance understanding of attentional control and sport performance.
Finally, the ambiguous findings on basic information processing capacities of athletes in Chapter IV require future research endeavor which is highlighted in the next section.

**Implications for future research when studying basic cognitive adaptations through sport**. First, when attempting to study cognitive adaptations through sports, researchers typically utilize a group-contrast paradigm—athletes vs. non-athletes; skilled vs. less skilled athletes; experts vs. novices—to test if these groups differ on standardized cognitive tests. Group differences on these test scores are often then interpreted as evidence for cognitive adaptations due to extended practice if these are in favor of the expert group (Nougier, Ripoll, & Stein, 1989; Nougier, Stein, & Bonnel, 1991; Nougier & Rossi, 1999; Pesce, Tessitore, Casella, Pirritano, & Capranica, 2007; Vestberg et al., 2012; Voss et al., 2010). However, this approach does not allow inference of a causal relationship and cannot answer the question whether engagement in team sports leads to improvements on cognitive ability tests, or whether enhanced cognitive abilities lead people to engage in team sports in the first place, increased chances of progressing to better teams, and decrease the likelihood of dropping out. Nor would scientists seriously investigate, for example, the height of a group of basketball players and non-basketball players and infer that basketball players adapted to the constraints of basketball by increasing in height. Hence, researchers cannot use the common inter-group paradigm (e.g. athletes vs non-athletes) because it does not allow inference of a causal relationship. Thus, the only method of studying certain adaptations is an experimental or longitudinal design, for example by comparing groups of suitably matched participants of which one, for example, engages in a specific soccer training

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9 See Appendix VII and VIII for more detail.
program, the other group engages in physical activity comparable to soccer, and the
last group acts as control without physical activity. I am not familiar with a single
study adopting this approach to provide evidence for the broad transfer hypothesis.
Hence, in this thesis I only address the question—based on my own data and the
existing literature—whether there is a relationship between general cognitive abilities
such as WM, attentional control, and superior team sport performance.

Moreover, it seems necessary that future research should control for several
other potential confounding variables: (i) that the different groups do not differ in the
time spent in other activities (e.g., action-video game playing) that might potentially
cause cognitive adaptations, and (ii) that the different groups do not differ in any
other state or trait variables that might account for superior performance in test
situations (e.g., competitiveness). In addition, fitness levels and reaction time need to
be carefully controlled as these might be confounded with the variables in interest.

A further problem when interpreting the results from different studies and
comparing these with one another is the highly diverse range of tasks and paradigms
utilized in the respective studies. An example illustrative of this problem is the
differences in the tasks of Vestberg et al. (2012) and the WMC tasks in our studies
which are both designed to measure executive functions. The results differed
substantially depending on the task, which is unfortunate because both studies
attempted to address the question whether successful team sport athletes have
superior attentional control capacities compared to less successful or non-athletes
and not whether athletes can perform a specific cognitive test more successfully. For
this reason it is problematic to compare results from different studies using different
tasks and paradigms (Memmert & Furley, 2010, Appendix VIII). This problem is
further amplified if the psychometric properties of the measures used—especially the
validity question—are unclear. Hence, currently a lot of the work on the
sport/cognition relationship is highly paradigm specific and exploratory in its nature
as two or three groups that differ on some level of their sport experience are
compared on more or less randomly chosen cognitive tasks. This paradigm-oriented
research strategy—which prevails in most areas of experimental psychology—is
problematic in advancing unified theoretical models (Meisner, 2011; Memmert &
Furley, 2010, Appendix VIII), also in the field of sport expertise.

Thus, in general, several exciting opportunities and potential topics that merit
further research remain for those interested in extending current knowledge and
understanding of the role of WM and controlled attention in the field of sports and
how these cognitive components relate to the field of sport expertise.

Concluding Remarks

Attention research celebrated a renaissance with the advent of World War II
due to an increased interest in applied questions concerning attention, such as how
pilots can focus their attention on task relevant information while blocking out
distractions, how they can divide their attention between controlling levers and
monitoring several displays, how long radar operators can focus their attention on the
screen, or whether some people are better at controlling their attention (Boucher,
2008). Paradoxically, attention research since then has been criticized for having lost
sight of real world behavior and that some of the most prominent research paradigms
in the study of attention “run the serious risk of excluding the exploration of
questions that are crucial to a fuller understanding of human attention and behavior”
(Kingston et al., 2003, p. 179). Therefore, the present thesis returned to more applied
research questions on attention by investigating the role of WM in controlling
attention in the applied field of sports and thereby followed the call of Neisser (1982)
who wrote 30 years ago that psychologists should base their research on everyday behavior.

Overall, this thesis has broadened and extended the sports attention and expertise literature, having both theoretical and practical implications, and offering some promising avenues for future investigations of WM in the area of sports.
References
References


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Appendix (missing)