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Working Memory Capacity as Controlled Attention in Tactical Decision Making

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The controlled attention theory of working memory capacity (WMC, Engle 2002) suggests that WMC represents a domain free limitation in the ability to control attention and is predictive of an individual's capability of staying focused, avoiding distraction and impulsive errors. In the present paper we test the predictive power of WMC in computer-based sport decision-making tasks. Experiment 1 demonstrated that high-WMC athletes were better able at focusing their attention on tactical decision making while blocking out irrelevant auditory distraction. Experiment 2 showed that high-WMC athletes were more successful at adapting their tactical decision making according to the situation instead of relying on prepotent inappropriate decisions. The present results provide additional but also unique support for the controlled attention theory of WMC by demonstrating that WMC is predictive of controlling attention in complex settings among different modalities and highlight the importance of working memory in tactical decision making.

Keywords: working memory, individual differences, attention, decision making, distraction, sport

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. Further, they 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 yet he suddenly notices a wide "corridor" and decides for a running play instead. In the present article, we investigate whether certain athletes are more likely to be successful in these hypothetical sport situations, as recent research in cognitive psychology suggests (e.g., Engle, 2002) that the limited-capacity working memory (WM) system may be useful in understanding performance in such high-interference situations.

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Working Memory Capacity as Executive/Controlled Attention

According to Kane and Engle (2002), WM is important in our daily life because it allows for efficient information processing by maintaining, updating, and retrieving information relevant to the task goal while ignoring or suppressing competing information that is not relevant for the current situation. They further suggest that the WM system is especially important in situations of interference in which one has to allocate attentional resources to relevant stimuli and quickly decide among competing responses or override prepotent and inappropriate responses. Evidence for this assumption has been derived from a series of studies demonstrating that measures of WM capacity (WMC) have been successful in predicting performance in situations affording controlled attention in the presence of interference (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, or executive 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, Kane, Bunting, Hambrick, Wilhelm, & Engle, 2005; Kane, Bleckley, Conway, & Engle, 2001; Engle, 2002). Thus, the term *working memory capacity* 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, 2007, p. 23).

The terms *executive attention* and *controlled attention* are used synonymously at this point. Both of them are frequently used in the literature and usually refer to the same processes. The term *executive attention* emphasizes the family resemblance to other theories of executive function, executive control, and executive attention (e.g., Baddeley, 1986; Norman & Shallice, 1986), whereas the term *controlled attention* is more concrete and sizeable. Thus, the term *controlled attention* will be used in the following text.

The controlled attention theory of WMC is derived from Baddeley and Hitch's multicomponent WM model (Baddeley & Hitch, 1974) but emphasizes the processing aspect of WM more compared with the original model. Guided by the controlled attention theory of WMC, a large body of research has been conducted linking WMC to higher order cognition (Kane et al., 2004). In this line of research, the so-called WMC measures emerged that are among the most widely used measurement tools in cognitive psychology today (Conway et al., 2005). Participants generally have to memorize digits or words in WMC measures while solving a demanding, secondary processing task such as verifying equations. In this respect, these tasks measure the ability of individuals to keep task-relevant information in a state of heightened activity during the execution of a cognitive processing task.

The main tenet of the controlled attention theory of WMC is that WMC tasks predict complex cognitive behavior such as reading comprehension (Daneman & Carpenter, 1980), language comprehension (King & Just, 1991), reasoning (Kyllonen & Christal, 1990), or even bridge playing (Clarkson-Smith & Hartley, 1990), because of the domain general controlled attention component shared by these tasks and the WMC tasks. 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 (e.g., Engle, 2002). More direct evidence for this claim has been derived by showing that WMC is not only predictive of high-level ability test scores but also of performance on low-level selective attention tasks, which are outlined below.

WMC in Avoiding Auditory Distraction

A fundamental question in psychology is how people stay focused on the task they are performing while ignoring internal and external distraction. Research on the topic of how individuals stay focused in distracting environments emerged during World War II, as the U.S. military was interested in distinguishing among people who were skilled at this feat and people who were not. One task that emerged in this endeavor was the dichotic listening task by Cherry (1953), in which participants have to repeat aloud a message presented to one ear while ignoring a different message presented to the other ear.

Broadbent (1958) developed his influential theory of selective attention partly based on work using the dichotic listening procedure. In a nutshell, Broadbent's selective filter theory of attention suggests that external information is filtered out of awareness at an early stage if it is identified as irrelevant on its basic physical properties (e.g., pitch, color, orientation) for a person's current concerns. Various findings (e.g., Moray, 1959; Treisman, 1960) have challenged the claims of Broadbent's theory by demonstrating that not all irrelevant information is filtered out of awareness. In this respect, Moray (1959) and later Wood and Cowan (1995) provided evidence that some participants reported hearing their own name in dichotic listening studies presented on the unattended auditory channel. Conway, Cowan, and Bunting (2001) identified WMC as a key moderating variable in distinguishing people who identified their name in the unattended channel from people who did not report hearing their name. Specifically, the study showed that individuals scoring high on WMC measures were less likely to detect their name (20%) compared with individuals scoring low on WMC (65%). Conway et al. (2001) suggest that low-WMC individuals were more likely to detect their own name in a dichotic listening task, as they could not focus their attention as well as high-WMC individuals on the primary shadowing task. Interestingly, Colflesh and Conway (2007) further reported that high-WMC individuals (66.7% detected their name) were more likely to detect their name compared with low-WMC individuals (34.5% detected their name) when the task required them to shadow words on one ear and listen for their name on the other ear. This finding suggests that high-WMC individuals not only have the ability to stay highly focused on the task at hand while ignoring distraction, but also are efficiently able to "zoom in" and "zoom out"—controlling their attention—depending on the task demands.

Moreover and of relevance for the current study, Kane et al. (2007a) reported that WMC did not only reliably predict attentional control in the laboratory, but further predicted people's subjective experience of mind wandering in daily life. Using an experience-sampling methodology, the authors found that low-WMC people reported more task-unrelated thoughts than high-WMC individuals in demanding everyday activities that required considerable effort and focused concentration.

WMC in Resolving Response Competition

Further studies have demonstrated that high-WMC individuals are not only more efficient at blocking out irrelevant internal and external information, but also show superior performance on interference tasks such as the Stroop task (Kane & Engle, 2003; Long & Prat, 2002); the antisaccade task (Kane, Bleckley, Conway, & Engle, 2001; Unsworth, Schrock, & Engle, 2004), and flanker tasks (Heitz & Engle, 2007).

In a respective study using the antisaccade task, Unsworth et al. (2004, see also Kane et al., 2001) presented a flashing box to high- and low-WMC people on either the left or the right side of the computer screen and subsequently asked them to identify a target either on the same side (prosaccade condition) as the flashing box or on the other side (antisaccade condition). In the prosaccade condition, the instruction was to look toward the stimulus, whereas in the antisaccade condition, participants were asked to look in the opposite direction. Thus, participants had to voluntarily move their eyes away from the cue toward the target in the antisaccade condition or prevent their attention from being reflexively captured by the cue altogether. In the prosaccade condition, participants can allow their attention to be reflexively drawn toward the cue. Both conditions require the establishment of a goal-oriented task set, but only the antisaccade condition, in which the goal conflicts with habit, requires the maintenance of the goal in a highly active state for accurate responding by actively blocking or inhibiting the reflexive tendency of moving the eyes toward the cue. Both Unsworth et al. (2004) and Kane et al. (2001) reported that high-WMC subjects were significantly better in the antisaccade condition than low-WMC subjects, whereas no differences were evident in the prosaccade condition. The authors interpreted this result as being indicative of low-WMC individuals being less likely to maintain the task goal—look away from the flash—in an heightened state of activity because they took longer to select the weaker but situation-appropriate response of looking away from the flash.

Similar findings were evident in the Stroop task (Kane & Engle, 2003), in which subjects have to name the color of printed color words, such as the word *RED* printed in black ink. Just like the antisaccade task, the Stroop task requires participants to maintain one single crucial goal: name the color of the ink in which the word is printed. The central part of the task is that the word and ink color can be either congruent (word *RED* printed in red ink) or incongruent (word *RED* printed in blue ink). As humans are used to reading out printed words, there is a strong predisposition to make a situation-inappropriate response in the incongruent trials (Kane & Engle, 2003). Therefore, the authors argue that actively maintaining the task goal while blocking the strong inappropriate tendency of reading the word requires controlled attention and thus performance on the Stroop task should be sensitive to individual differences in WMC. To test this idea, Kane and Engle (2003) varied the proportion of congruent and incongruent trials in a classic Stroop paradigm. In line with the controlled attention theory of WMC, the most pronounced WMC difference in Stroop performance emerged in the condition in which 75% of the trials were congruent. Low-WMC individuals made significantly more errors compared with high-span individuals when participants could usually rely on their reflexive tendency of reading out the word regardless of the ink color in 75% of the trials and only had to actively maintain the task goal of naming the ink color in 25% of the trials.

The outlined studies on response competition indicate that high-WMC subjects can not only use their superior attentional control for blocking out distraction, but also for resolving response competition in interference situations. In conclusion, high-WMC people are better at acting situation appropriately instead of relying on reflexive situation-inappropriate responses.

The Present Research

The reviewed cognitive psychological literature suggests that individual differences in WMC reliably predict the regulation of thought and behavior, with low-WMC people being more prone to both distraction and impulsive error (e.g., Engle, 2002). To date, this conclusion is almost exclusively derived from simple laboratory-based attention tasks (see Kane et al., 2007a, for an exception) and it remains unclear whether this association transfers to more complex everyday performance activities, such as competitive sports. Relevant to the present research, Kane et al. (2007a) suggested that the ability to control attention is especially important during challenging activities in contexts providing concurrent distraction and interference from prior experience. Considering the immense importance of WMC in explaining complex cognition (Engle, 2002), it is surprising that to our knowledge no endeavors have been undertaken in exploring the role of WMC in sport performance situations. In this respect, we argue that the field of team sports is a highly suitable scenario for testing the predictions of the controlled attention theory of WMC in a representative performance setting (Furley & Memmert, 2010). Therefore, we both (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. With respect to (i), Williams and Ericsson (2005) argue that the field of sports offers a fruitful domain in which to explore the validity of models developed in other fields, as team sports, for example, are performed in dynamic, ever-changing environments under conditions of extreme stress and interference. In terms of (ii), 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 the present research, we draw on Vogel and Awh's (2008) argument that cognitive theory development can substantially benefit from combining an individual-difference approach with an experimental approach. In this endeavor we use WMC as an individual difference variable to illuminate the underlying cognitive mechanisms necessary for athletes to overcome distraction and interference in sport-specific decision-making situations. The present study is the first to address the question of whether sufficient central resources (i.e., WMC) might be beneficial for athletes in high-interference situations, as these call for controlled attention. In this respect, we test if WMC is not only predictive of controlled attention in simple laboratory based attention tasks (e.g., dichotic listening or antisaccade task) but also in representative team-sport situations. In addition, we propose that instead of treating individual differences as error variance (Cronbach, 1957), sport psychological theory development can substantially benefit from systematically investigating individual difference variables in experimental settings. Specifically, we address two questions: (i) Are athletes with a greater WMC better at blocking out distraction while focused on a sport-specific performance task (Experiment 1)? (ii) Are athletes with a greater WMC more efficient at resolving response competition in a tactical decision-making task instead of relying on prepotent situation-inappropriate decisions (Experiment 2)?

In Experiment 1, we draw on the findings from Conway et al. (2001) and investigate whether high-WMC athletes are better at focusing attention on sport-specific decision making while blocking out auditory distraction. As highlighted by the basketball free throw example in the introductory paragraph, it is essential for athletes to efficiently focus their attention on successful performance while blocking out external distractions, such as crowd noise. Experiment 2 is derived from the antisaccade (Unsworth et al., 2004; Kane et al., 2001) and Stroop (Kane & Engle, 2003) findings and investigates whether high-WMC athletes are better at adjusting their tactical decision according to the current situation instead of relying on prepotent context-inappropriate decisions. As we already mentioned, this is an important feat in team sports. For example, some players might "blindly" follow tactical instructions they receive from coaches or always rely on their dominant habitual response instead of flexibly adjusting their decisions or actions to the current situation.

Experiment 1: WMC in Avoiding Distraction During Tactical Decision Making

The rationale for Experiment 1 was twofold: (i) We attempted to apply the controlled attention theory of WMC to the domain of sports by testing whether individual differences in WMC would also be predictive of controlling attention in a task that is fairly representative of the demands of a basketball game: basketball players making a time-constrained tactical decision in the context of crowd noise. (ii) Moreover and more theoretically motivated, we attempted to investigate whether the pattern of results found in dichotic listening studies (Conway et al., 2001), in which participants have to attend to and ignore information within the auditory modality, is similar if participants are required to attend to visual information to make a situation-adequate decision and ignore auditory information. Opposing assumptions exist concerning whether each sensory modality draws on a common pool of attentional resources (Santangelo, Belardinelli, & Spence, 2007; Sinnett, Costa, & Soto-Faraco, 2006; Sörqvist, Halin, & Hygge, 2010) or whether each sensory modality has its own independent pool of attentional resources (Duncan, Martens, & Ward, 1997; Schneider & Detweiler, 1988; Soto-Faraco, Morein-Zamir, & Kingstone, 2005). According to modality-specific views, both attentional capacity and temporary storage is peculiar to each modality and representations in one modality should not interfere with representations in another. On the other hand, recent studies have provided the first evidence that high-WMC individuals are less distracted by irrelevant speech (Sörqvist, Halin, & Hygge, 2010) when recalling visually presented material or comprehending texts. Therefore, we contrast the opposing predictions to find out whether WMC can predict attentional control when the primary task and the distraction condition reside in separate modalities.

For this purpose, we identified high- and low-WMC basketball players and had them perform a demanding time-constrained tactical decision-making task under auditory distraction conditions in which an irrelevant stream of words was presented over headphones with their own name being presented at a specified point in time. Similar to the findings of Conway and colleagues (2001) and in line with the controlled attention theory of WMC, we hypothesized that (i) high-span athletes would be less likely to notice their own name compared with low-span subjects; and (ii) that high-span subjects would perform better at the demanding time-constrained tactical decision-making task compared with low-span subjects as a consequence of being more focused on the task.

As we were interested in applying the controlled attention theory of WMC to more representative everyday performance situations, we directly tested whether individual differences in WMC are further related to distractibility in everyday life. To this end, we measured distractibility in everyday life with the Cognitive Failure Questionnaire (CFQ; Broadbent, Cooper, FitzGerald, & Parkes, 1982). Forster and Lavie (2007) found that individuals reporting higher distractibility in everyday life also experienced more distractibility in the laboratory using the perceptual load paradigm. Therefore, and in line with the findings of Kane et al. (2007a), we expected to find a negative relationship between the WMC scores of athletes and their self-reported distractibility in everyday life (iii).

Method, Materials, and Stimuli

Subject Selection. For the purpose of this study, we used an extreme group design, which is a common procedure in the controlled attention theory of WMC literature (Conway, et al., 2001; Colflesh & Conway, 2007; Engle, 2002; see Conway et al., 2005, for more detail on the use of extreme group designs within the controlled attention theory of WMC). Sixty-nine basketball players took the counting span task (36 male and 33 female). As the distribution of WMC scores obtained differed significantly from normality—showing a very pointed distribution with the vast majority of scores centered around the mean ($Z_{\text{kurtosis}} = 4.39$)—and from the distribution found in Kane et al. (2004) using the counting span task, we decided to classify the highest 20% of the distribution as high-span athletes and the lowest 20% as low-span athletes to diminish the risk of misclassifying an individual. Thus, the sample invited to participate in the second part of the study consisted of 28 participants (16 male and 12 female; $M_{\text{age}} = 27.2$) who had been playing basketball for an average of 12.5 years at an amateur to semiprofessional German club level. Fourteen participants were assigned to the low-span group (WMC: $M = .51$; $SD = .10$) based on their counting span performance and 14 participants were assigned to the high-span group (WMC: $M = .82$; $SD = .07$). The differences between the WMC groups were in line with previous research using extreme group designs (e.g., Kane et al. 2001; Kane & Engle, 2003). Neither age, gender, nor expertise significantly influenced the pattern of results. Informed consent was obtained from every participant before commencing the experiment. The study was carried out in accordance with the Helsinki Declaration of 1975.

Counting Span. In Experiment 1 we used a counting span task (see Kane et al., 2004, for a detailed description), as the simplicity of the processing task makes it ideal for almost any population of participants (Conway et al., 2005). The instructions were presented on the computer screen. The counting span task involved counting specific shapes among distractors and then remembering the count totals for later recall. Each stimulus display contained randomly arranged dark blue circles, light blue circles, and dark blue squares. The task of the participants was to count aloud the dark blue circles and name aloud the count total at the end. A Recall cue ("???") occurred after two to six stimulus displays at which participants had to write down their memorized count totals in the order they had been displayed in. The participants counting span score was a partial credit load score (cf. Conway et al., 2005). A partial credit load score represents the sum of all correctly recalled elements—whereby a correctly recalled item from a set containing two items receives 2 points, and a correctly recalled item from a set with 6 items receives 6 points—divided by the maximum possible score.

Cognitive Failure Questionnaire (CFQ). We used the CFQ (Broadbent et al., 1982; Klumb, 1995) to assess participants' susceptibility to distractibility. The CFQ is a 25-item questionnaire on which participants have to rate the frequency of 25 common types of cognitive failures on a 5-point Likert scale ranging from zero (*never*) to 4 (*very often*). The sum of the individual items represents the total CFQ score, with high scores being reflective of more distractibility. Two example items of the CFQ are as follows: "Do you start doing one thing at home and get distracted into doing something else (unintentionally)?" and "Do you read something and find you haven't been thinking about it and must read it again?" Previous research has shown that CFQ scores are significantly correlated with ratings of respondents by their spouses (Broadbent et al., 1982), with frequency of car accidents (Larson & Merritt, 1991), injuries from falling (Larson, Alderton, Neideffer, & Underhill, 1997), and work accidents (Wallace & Vodanovich, 2003). Klumb (1995) reported sufficient criterion-related correlations between the German CFQ and everyday problems such as forgetting to return a borrowed book or loosing things. Reliability scores for the German version were also sufficient (Cronbach alpha .82; split-half coefficient according to Spearman–Brown, .83).

Complex Decision-Making Task Under Distraction Conditions. For the complex decision-making task, we selected stills from television broadcast basketball games. Every picture involved a player holding the ball with various tactical decision options. The player holding the ball was marked with a bold yellow arrow so that participants could identify the ball holder immediately. Two independent basketball experts (both in possession of the second highest basketball coaching license in Germany) rated the pictures according to the best decision for every picture. We selected those pictures for which the basketball experts had rated the tactical decision concordantly. This left us with 116 stimuli for the tactical decision-making task. Participants had to make their tactical decisions by pressing a corresponding key on the keyboard: the "c" key to *shoot*; the "n" key to *cut/dribble*; and the "space" bar to *pass* the ball. Participants were instructed to respond as quickly and accurately as possible in the three-alternative, forced-choice decision task. Every basketball stimulus was presented for 1000 ms and preceded by a 750-ms fixation cross. Responses were collected during the actual stimulus presentation and during the following fixation period. The stimulus presentation did not terminate after the response was given and thus the presentation duration was always identical.

During the tactical decision-making task, a distracting auditory message was presented to the participants through stereo headphones at a constant volume. The distracting auditory stream contained 300 di- and monosyllabic words recorded in two different monotone female voices at a rate of 80 words per minute and lasted during the entire tactical decision-making task. The onset of the distracting auditory stream started simultaneously with the tactical decision-making task. After 56 trials (98 s), the female voice speaking the distracting message altered and a different voice uttered the irrelevant message. Further, the first name of every subject was digitally inserted by the same female voice. Exactly 250 ms after the stimulus onset of the 103rd (after 180.25 s) decision-making trial, the name of the participant appeared in the distracting auditory stream. The order of the di- and monosyllabic words was identical except for the names across all subjects.

Procedure

Subjects were first tested individually in a quiet laboratory on the counting span task and filled out the CFQ questionnaire together with a questionnaire gathering demographic data. Subjects assigned to the high-span and low-span WM groups based on their counting span scores were asked to come to the laboratory a second time to complete the complex decision-making task. Participants were informed that the study investigated tactical decision-making skills in basketball under distraction conditions. The instructions for the complex decision-making task were presented on a 19-inch computer screen. E-prime Professional (Version 2.0; Psychological software, 2007) was used to present the stimuli and collect the judgments on a 19-inch computer screen placed 60 cm away from the subjects. To familiarize themselves with pressing the corresponding keys in the decision-making task, participants first performed a practice trial containing 30 trials without the distracting auditory message. The 30 practice stimuli were additional to the 116 experimental stimuli, and none of them were repeated throughout the procedure. After the practice block, participants were informed about the distracting auditory message and that their decisions and reaction times would now be recorded. Participants were explicitly told to try to ignore the distracting auditory message and concentrate on the tactical decision-making task. Both accuracy and speed on the tactical decision-making task were emphasized. After completing the decision-making task, subjects were asked several questions regarding the distracting auditory message: (i) did you notice anything unusual about the distracting message? If yes, what? (ii) Did you notice that the voice of the speaker of the irrelevant message changed? (iii) Did you notice your first name in the irrelevant message?

Data Analysis

We conducted Pearson's chi-square analysis to determine associations between WMC and name/voice-change detection. Differences in tactical decision-making performance—defined as the percentages of tactical decisions in line with the expert ratings—between the WMC groups were analyzed with the nonparametric Mann–Whitney *U* test. The strength of the relationship between the WMC scores and the CFQ scores was determined using Pearson's correlation coefficient.

Results and Discussion for Experiment 1

When analyzing the retrospective reports, we found a significant association between the WMC of basketball players and whether they detected their name (see Figure 1) during a demanding complex decision-making task χ^2 (1, $N = 28$)

= 9.333; p = .002, two-tailed. Based on the odds ratio, the odds of low-WMC individuals detecting their name while concentrating on a complex decision-making task were 15 times higher than for high–working memory span individuals. As the group sizes were small in the study, we further computed Fisher's exact test, which revealed that the probability of obtaining the pattern of results by chance is only .006, two-tailed (under the assumption that high- and low-span subjects are actually equally prone to detecting their name in the irrelevant message). In line with hypothesis (i), the low-span subjects detected their own names more often. No differences between the high– (71% noticed) and the low–working memory span groups (64% noticed) were evident in detecting that the voice had changed in the to-be-ignored audio stream ($\chi^2 < 1$).

The low-span group performed reliably worse (see Figure 2) on the speeded tactical decision-making task compared with the high-span group, supporting hypothesis (ii); U = 175.00, z = 3.544, p = .0001, two-tailed; d = 1.70. Both the findings on name detection and performance are in line with previous findings using the dichotic listening procedure (Conway et al., 2001) and provide further support for the controlled attention theory of WM in a more representative performance setting. Thus, high-WMC individuals can use their superior attentional control to inhibit a distracting auditory message and stay focused on the tactical decision-making task when the sole purpose of the task is to make appropriate tactical decisions in a distracting environment.

Of further interest and in line with hypothesis (iii), we found WMC to be significantly correlated to everyday distractibility as measured by the CFQ when all of the 69 participants who took the counting span measure and the CFQ were included in the analysis, r = –.372, p = .001, two-tailed. This finding is in line with the idea that WMC measures are associated with attentional control not only in laboratory tasks but also in everyday activities (cf. Kane et al., 2007a). For this reason, WMC measures seem to be a promising tool for identifying people who are skilled at controlling their attention in everyday activities.

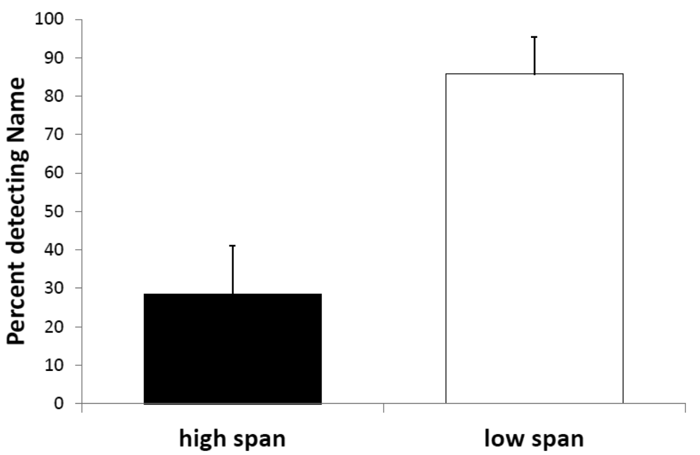

Figure 1 — The proportion of high– and low–working memory span participants detecting their name during a demanding tactical decision-making task in Experiment 1. Error bars indicate standard errors.

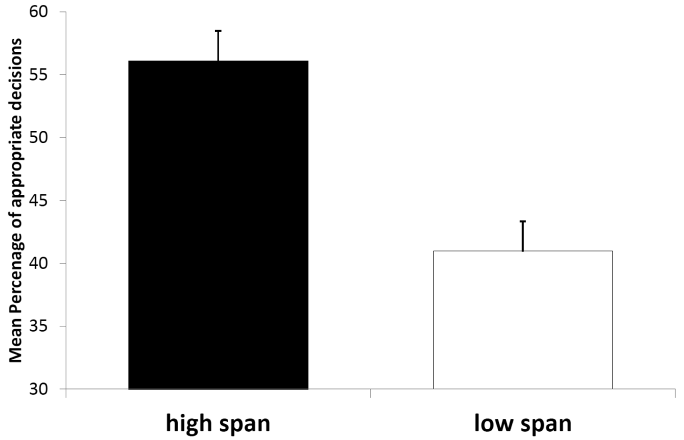

Figure 2 — Mean percentages of appropriate decisions in the speeded decision-making task as a function of working memory capacity in Experiment 1. Error bars indicate standard errors.

The results presented provide additional but also unique support for the controlled attention theory of WMC by showing that WMC seems to remain a successful predictive instrument in a representative basketball decision-making scenario. Athletes scoring high on WMC were better able at focusing their attention on tactical decision making while blocking out irrelevant auditory distraction compared with athletes scoring low on WMC. The significant correlation between the self-reported cognitive failures of basketball players in everyday life and the WMC scores further emphasize this argument. Further, we demonstrate that WMC is predictive of controlling attention between different modalities in a 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. This finding is of theoretical interest as it directly contrasts with the modality-specific views (Duncan et al., 1997; Schneider & Detweiler, 1988; Soto-Faraco et al., 2005).

Experiment 2: WMC in Resolving Response Competition in Tactical Decision Making

Experiment 2 tested the predictive power of WMC in resolving response competition during sport-specific decision making. As reviewed above, previous research suggests that high-WMC individuals 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 action tendencies and action plans. The term *attentional control* has its roots in Norman and Shallice's (1986) concept of a "supervisory attention system (SAS)," which was adopted as the central executive component of Baddeley's (1986) multicomponent WM model. According to Norman and Shallice (1986), behavior is controlled at two levels: the first is fairly automatic and based on habits and predefined schemas—such as executing a well-practiced predefined offensive play in American football or ice hockey. The other level is a mechanism for overriding such habits or schemas and was termed the SAS. The SAS is used when habit patterns or prepotent schemas are no longer adequate, such as if the defensive team anticipates a specific offensive play and defends accordingly. Then the decision maker is forced to adapt his/her behavior according to the situation instead of relying on the well-learned response schema.

Given the enormous amount of information that bombards players of team ball games, it is often not possible for a player to consider all the tactical decision-making possibilities in complex situations (Furley, Memmert, & Heller, 2010; Furley & Memmert, 2010; Memmert & Furley, 2007). In this respect, coaches of team ball sports frequently use tactical instructions and practice offensive plays to direct a player's focus of attention (Furley et al., 2010) in the hope of assisting his/her tactical decision-making process. These tactical instructions—such as those given during a team time-out—can facilitate decision making, if a game situation evolves that "fits" to the instruction given. The following is an example: an ice hockey coach tells his players in a team time-out that the opposing goalkeeper has difficulty holding on to the puck and therefore long-distance shots are likely to result in rebounds and, shortly after the team time-out, a situation emerges in which a long-distance shot would be a appropriate tactical move. On the other hand, the same tactical information may be inappropriate if a situation emerged in which a long-distance shot would not be a appropriate tactical decision. Relevant to the current study, Furley et al. (2010, see also Memmert & Furley, 2007) demonstrated that tactical instructions, intended to facilitate decision making, can potentially impede experienced athlete's decision making. The results of Furley et al. (2010) indicate that decision making became less accurate if the tactical information given by the coach suggested an alternative tactical decision in comparison with the tactical decision that the subsequent game situation afforded. This theoretical assumption can be demonstrated by the following example: a basketball point guard might not pass to the unmarked teammate under the "hoop" but instead passes to the closely marked shooting guard at the 3-point line because of the intended offensive play announced by the coach during the last time-out. According to the attentional control theory, we did not assume to find WMC differences in situations in which there is no competition to be resolved (e.g., when tactical information received from the coach "fits" a subsequent game situation—valid information) but in situations in which players have to use their SAS to override the prepotent tendency of following the information of the coach and adapt their decision according to the game situation (e.g., when tactical information received from the coach does not "fit" the following game situation—invalid information). To test this assumption, we identified high- and low-WMC ice hockey players and had them perform a similar time-constrained tactical decision-making task as in Experiment 1. Only this time the task did not include auditory distraction, but instead some decision-making trials were preceded by a simulated team time-out in which participants received tactical information from a virtual coach. This tactical information could either be valid for the subsequest game situation—that is, following the tactical information was a appropriate solution for the game situation—or be invalid—that is, following the tactical information was not a appropriate solution for the game situation. Similar to such findings of those of Kane et al. (2001) or Kane and Engle, (2003) and in line with the controlled attention theory of WMC, we hypothesized that (i) high-span athletes would be less likely to "blindly" follow the tactical information of a virtual coach when it was inappropriate for the subsequent game situation and instead adapt their tactical decision according to the situation; (ii) no WMC differences would be evident in situations in which no response competition existed.

Method, Materials, and Stimuli

Subject Selection. Fifty-five male ice hockey players (age: M = 24.71, SD = 4.21; playing experience: M = 18.93, SD = 4.582) took part in the study. Again we used an extreme group design, only this time we prescreened our participants with the automated operation span task, as this task requires a lot less experimenter time, has proven to correlate well with other WMC measures, and has excellent psychometric properties (Unsworth, Heitz, Schrock, & Engle, 2005). As in the original operation span task (Turner & Engle, 1989), participants have to solve math problems while trying to remember an unrelated set of letters. The score was the number of correct items recalled in the correct position. See Unsworth et al. (2005) for full task details. Altogether we screened 55 professional to semiprofessional male hockey players competing between the first and third league in Germany. The distribution of WMC scores in our ice hockey sample (M = 39.82, SD =18.3) was almost identical to the distribution reported in Unsworth et al. (2005; M = 39.16; SD = 17.4). This time, the WMC scores were normally distributed and we classified, in line with previous research (e.g., Conway et al., 2001; Colflesh & Conway, 2007; Engle, 2002; Conway et al., 2005), the participants scoring in the upper quartile as high-span athletes and those scoring in the lower quartile as low-span athletes. Thus, our sample consisted of 15 high-span (WMC: M = 63.33; SD = 5.5) and 15 low-span (WMC: M = 17.53; SD = 5.7) participants. Neither age- nor expertise-related differences were evident within the group. Informed consent was obtained from every participant before commencing the experiment. The study was carried out in accordance with the Helsinki Declaration of 1975.

Ice Hockey Decision-Making Task. The tactical decision-making task was similar to the basketball decision-making task with a few major changes. We selected stills from television broadcast ice hockey games. Every picture involved a player holding the ice hockey puck in an offense situation with various tactical decision options. Again the player holding the puck was marked with a bold yellow arrow so that participants could identify the puck holder immediately. Two independent ice hockey experts (both in possession of the second highest ice-hockey coaching license in Germany) rated the pictures according to the best decision for every picture. We selected those pictures for which the experts had rated the tactical decision concordantly. This left us with 90 stimuli for the tactical decision-making task. The ice hockey decision-making task contained two types of experimental trials: (i) regular trials in which participants only had to make a tactical decision for the presented game situation and (ii) team time-out trials in which a team time-out was simulated before a game situation was presented for which a tactical decision had to be made.

Regular Trial. In these trials, participants had to make their tactical decisions by pressing a corresponding key on the keyboard: the "s" key to *shoot*; the "p" key to *pass*; and the "space" bar for a *solo effort*. Participants were instructed to respond as quickly and accurately as possible in the three-alternative-forced-choice decision task. Before every stimulus presentation, a fixation cross appeared with the instruction to place the fingers on the corresponding key and press any key when ready. Every ice hockey stimulus was presented for 1000 ms and was followed by a mask lasting for 3000 ms. Thus, tactical decisions were collected for 4000 ms before the next self-paced fixation cross appeared on the screen. Every participant completed 60 regular trials: 20 for which the experts had agreed on shooting being the best tactical decision, 20 pass, and 20 solo effort.

Team Time-Out Trial. In these trials, a regular trial was preceded by a screen simulating a team time-out taken by the coach to give the players tactical information for the upcoming offensive play. Two types of information were given in the team time-out both concerning the goalkeeper of the opposing team. One type of information recommended passing the ball in front of the goal, whereas the other type recommended shooting. Both were worded in two different ways so that there were four different tactical messages altogether. An example for a team time-out recommending shooting was, "there have been many rebounds after shots at goal as the opposing goal-keeper has difficulty holding on to the puck. Therefore, we need more long-distance shots." An example of a team time-out recommending a pass was "the opposing goal-keeper reacts really slowly to passes in front of the goal and sticks to his goal-line. Thus, parallel passes in front of the goal are a promising option." At the end of the screen, participants were explicitly informed that this information should only be used if it is adequate for the game situation and they still have all three decision options available. After confirming that participants had read and understood the tactical information, they had to press any key to continue with the decision-making task. The following procedure was identical to the regular trials with the exception that after having made their tactical decision participants were asked whether a certain word had been present in the tactical information they had received during the time-out. If the word had been present, participants had to press the "j" key and the "n" key if it had not been present. This memory probe was included to assure that participants had stored the tactical information in their working memory, as is a common procedure in the WM literature (see Soto, Hodsoll, Rotshtein, & Humphreys, 2008, for a recent review).

The ice hockey decision-making task included 30 team time-out trials. Fifteen team time-outs recommended passing and 15 recommended shooting. In 66% of the times, the team time-out information was valid, that is, was followed by a game situation for which the experts had rated the recommended tactical decision as the best tactical solution for the presented situation. Ten out of 15 times, a shoot situation followed when shooting was recommended in the team time-out, and 10 out of 15 times passing was the best option when passing was recommended. These trials are referred to as valid team time-out trials. On the other hand, in 5 out of 15 times, the recommended behavior during the team time-out was not the optimal decision for the subsequent situation but instead called for a different decision; that is, when passing was recommended, a situation followed in which shooting was the optimal decision and vice versa. These trials are referred to as *invalid* team time-out trials. The ratio of valid-to-invalid trials was based on Kane and Engle (2003), who demonstrated that WMC differences in resolving response competition are most pronounced if participants can usually rely on their reflexive tendency (in this case following the tactical information) and only actively have to rely on controlled attention to override the prepotent response on a small proportion of trials.

Procedure

Subjects were first tested individually in a quiet laboratory on the operation span task and filled out a questionnaire gathering demographic data. Subjects assigned to the high-span and low-span WM group based on their operation span scores were asked to come to the laboratory a second time to complete the ice hockey decision-making task. Participants were informed that the study investigated tactical decision-making skills in ice hockey. The instructions for the complex decision-making task were presented on a 19-inch computer screen. E-prime Professional (Version 2.0; Psychological software, 2007) was used to present the stimuli and collect the judgments on a 19-inch computer screen placed 60 cm away from the subjects. To familiarize themselves with pressing the corresponding keys in the decision-making task, participants first performed a practice trial containing 10 trials altogether: 6 regular trials with an equal number of optimal decisions for every response alternative and 4 team time-out trials (2 valid and 2 invalid). All trials were presented in random order. After the practice trials, participants were informed that the data recording was going to start and that the procedure was going to be identical to the practice trials.

Data Analysis

We analyzed the ratios of appropriate decisions—defined as matching with the prior expert ratings—and ratios of inappropriate decisions—defined as mismatching with the expert ratings—as a function of WMC in the different decision conditions with a series of Mann–Whitney *U* tests.

Results and Discussion for Experiment 2

Overall there was no difference between the high-span athletes and the low-span athletes in tactical decision making. Although the low-span group (M = 64.4% in accord with expert ratings; SD 5%) performed slightly worse on the speeded tactical decision-making task compared with the high-span group (M = 67.1% in accord with expert ratings; SD 5.4%), the difference failed to reach significance, $U = 77.00$, $z = -1.480$, $p = .139$, two-tailed; $d = 0.51$.

The trials following a team time-out, on the other hand, revealed significant differences between the low-span and the high-span group (see Figure 3). In line with hypothesis (i) and the controlled attention theory of WMC, low-span subjects failed to adjust their tactical decision to the demands of the game situation and "blindly" followed the instructions of a virtual coach even though it was not appropriate in that situation (as indicated by the expert ratings for the respective game situations), $U = 180.00$, $z = 2.912$, $p = .004$, two-tailed; $d = 1.24$ (Figure 3, rightmost bars). This result pattern remains unchanged when using the ratio of "correctly adapted" decisions as dependent measure instead of the ratio of "blindly" followed decisions as in the former analysis. High-span subjects were more sufficient at adjusting their tactical decision to the demands of the situation if the information they got during the team time-out was not appropriate for the following offensive game situation $U = 55.00$, $z = -2.460$, $p = .014$, two-tailed; $d = 0.91$ (Figure 3, middle bars). In support of hypothesis (ii), no WMC group difference were evident when the information players got during the team time-out

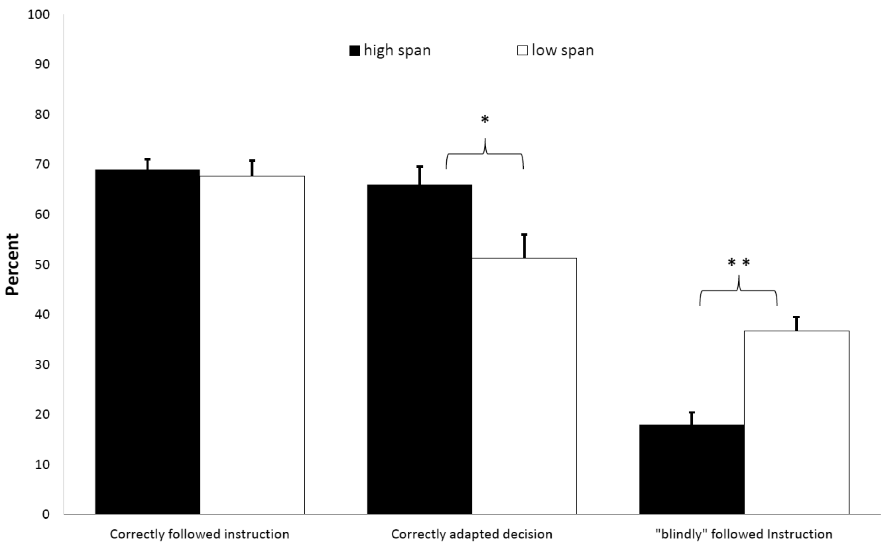

Figure 3 — Mean percentages of decisions following a team time-out as a function of working memory capacity in Experiment 2. Error bars indicate standard errors. $*p < .05$; $**p < .01$.

was valid for the subsequent game situation and no competing responses had to be resolved, as following the tactical information from the virtual coach was a appropriate solution for the respective game situation, $U = 110.500$, $z = -0.084$, $p = .933$, two-tailed (Figure 3, leftmost bars).

The results of Experiment 2 support the predictions of the controlled attention theory of WMC by showing that sufficient WMC resources are necessary for adequately resolving competing response tendencies in a complex sport decision-making context. In this respect, the current results extend previous findings showing that WMC is predictive of inhibiting a reflexive response in simple attention tasks—such as reading a written word or directing one's gaze to a flashing light—when these are situation inappropriate to a representative sport decision-making context. In conclusion, the results suggest that sufficient WMC is necessary in resolving conflict between competing action tendencies.

General Discussion

The results presented provide additional but also unique support for the controlled attention theory of WMC (Engle & Kane, 2004; Kane, Bleckley, Conway, & Engle, 2001; Kane & Engle, 2002, 2003) by showing that WMC seems to remain a successful predictive instrument in a complex sport-specific decision-making scenario. Athletes scoring high on WMC were better able at focusing their attention on tactical decision making while blocking out irrelevant auditory distraction compared with athletes scoring low on WMC in Experiment 1. In Experiment 2, high-WMC athletes were more successful at adapting their tactical decision making according to the situation instead of always relying on information they received from a virtual coach. Thus, the present results add to the growing body of evidence suggesting that sufficient WM resources are required for avoiding distraction and impulsive errors also in the field of team sport.

In Experiment 1, we demonstrated that WMC is 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 et al., 1997; Schneider & Detweiler, 1988; Soto-Faraco et al., 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. The findings from Experiment 1 add to the increasing evidence challenging modality-specific views of attentional resources by showing that high-WMC individuals are less distracted by irrelevant noise when attending to visually presented stimuli. In addition, the findings by Kane et al. (2007a) that high-WMC people are more absorbed in daily activities and therefore experience less mind wandering also suggest that WMC is predictive of focusing attention across different modalities in complex activities. In this respect, growing evidence suggests that WMC measures are a promising instrument of distinguishing among people who are skilled at staying focused on their task in interference-rich environments, also in sports.

Of further theoretical interest are the results of Experiment 2, as they indirectly illuminate the importance of the SAS or the central executive component of WM in resolving response competition during tactical decision making. Before discussing this point in more detail, it seems necessary to draw on the common distinction between controlled and automatic processing (Schneider & Shiffrin, 1977) in the sports literature (see Abernethy, Maxwell, Masters, van der Kamp, & Jackson, 2007 for a recent review). Of relevance to the present discussion, controlled processing is believed to rely heavily on WM, whereas automatic processing is not assumed to rely as heavily on WM resources (e.g., Schmidt & Wrisberg, 2004). Thus, a great deal of training in sports is actually undertaken to circumvent the limitations of WM and to automatize behaviors (Williams & Ericsson, 2005) so as to free valuable WM resources. In this respect, a highly practiced soccer player would not need to “waste” valuable WM resources for attending to the execution of dribbling the ball—as this has been automatized, or proceduralized (Anderson, 1982, Logan, 1988)—and instead can use the freed attentional resources to scan the field for open teammates. Therefore, team-sport athletes’ decision making seems to profit from sufficient WM resources, especially in situations requiring the resolution of competing decisions.

A further related series of findings by Beilock and colleagues (e.g., Beilock, 2008; Beilock & DeCaro, 2007, Beilock & Carr, 2005) on the relationship between WMC and mathematical problem solving seems highly pertinent regarding the results of Experiment 2. Drawing on dual-process theories of reasoning (for a review, see Evans, 2003), Beilock and DeCaro (2007) demonstrated that high-WMC individuals used different cognitive problem-solving strategies compared with low-WMC individuals. Dual-process theories assume two distinct processes—*associative* and *rule-based processes*—that are involved in reasoning and decision making. *Associative processing* is assumed to consist of similarity-based associations, which have emerged as a consequence of prolonged and repeated exposure to concurrent events and is believed to place only moderate demands on WM (e.g., Logan, 1988). On the other hand, *rule-based processing* is assumed to rely on symbolically represented explicit knowledge and therefore draws heavily on WM (e.g., Stevenson & Carlson, 2003). Beilock and DeCaro (2007) found that people approach difficult problems differently according to their respective WMC, in that high-WMC people tended to rely more on complicated rule-based strategies while low-WMC people relied more on simpler associative processing, probably because low-WMC people have less cognitive resources available for complicated rule-based computations. In this respect, the results of Experiment 2 also seem indicative of a simpler information-processing strategy of low-WMC athletes, whereas high-span athletes might have used a more demanding rule-based strategy because their higher WMC enabled them to use a more elaborate decision-making strategy. Although the findings from the current study may be interpreted in this manner, much work is needed to advance current theoretical and empirical understanding of the role of WM in sport decision making. Thus, a fruitful avenue for future research may be to directly examine various decision-making strategies as a function of WMC along lines similar to those that Beilock and DeCaro (2007) used for mathematical problem solving.

Despite the contribution of the novel findings of WMC on tactical decision making in team sports to the sport psychology literature, the present experiments are not without their limitation regarding the applied inferences. At this stage, the current findings 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 high-WMC athletes 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 giving "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 want to consider using WMC measures, for example, for screening, intervention, or even selection purposes.

It is our hope that other researchers will be stimulated to build on these first findings and extend current theoretical and applied understanding of the role of WM in sport decision making. After the predictive power of WMC has received more empirical support in the sports domain, future research endeavors might want to establish training interventions to improve WMC and in turn controlled attention in sports, as some studies have 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). 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-related functioning 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, considering that 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.

In conclusion, WM theory appears to be a valuable framework for guiding research and deriving testable hypotheses, also in the field of sports. 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 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.

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