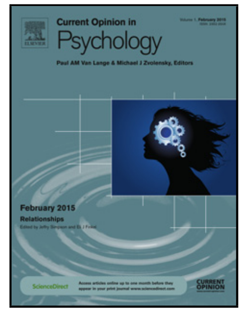

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The generalizability of working-memory capacity in the sport domain

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Highlights

- Working-memory (WM) capacity has been associated with sport-related skills
- The generalizability of findings from controlled experiments is unknown
- There is no evidence that sport experts possess a larger WM capacity
- Research should explore the WM capacity of particular types of players in sport
- Focus should be geared towards causal relationships rather than only correlations

Abstract

Working-memory capacity has been implicated as an influential variable when performing and learning sport-related skills. In this review, we critically evaluate evidence linking working-memory capacity with performing under pressure, tactical decision making, motor skill acquisition, and sport expertise. Laboratory experiments link low working-memory capacity with poorer performance under pressure and poorer decision making when required to inhibit distractions or resolve conflict. However, the generalizability of these findings remains unknown. While working-memory capacity is associated with the acquisition of simple motor skills, there is no such evidence from the available data for complex motor skills. Likewise, currently there is no evidence to suggest that a larger working-memory capacity facilitates the attainment of sport expertise.

The generalizability of working-memory capacity in the sport domain

There has been resurgence in the idea that general cognitive abilities are associated with sport expertise [1, 2]. In particular, working-memory (WM) capacity is popularly discussed due to its apparent connection with many skills in everyday life and in specific contexts such as sport. WM capacity is defined as the ability to control attention on task goals in the face of interference [3, 4].

WM capacity has been identified as influential in a range of sport-related skills [5, 6, 7]. This review will focus on three specific contexts in sport that have been demonstrated to be influenced by WM capacity: (a) performance under pressure, (b) tactical decision making, and (c) motor skill acquisition. Finally, we will discuss the (potential) relationship between WM capacity and sport expertise.

Performance under pressure

Successful skill execution under pressure is often attributed to the ability to ignore distractions, such as crowd noise or opposition taunts [8]. Given that attention control and avoidance of distraction are primary functions of WM capacity [9], it seems logical that WM capacity influences performance under pressure. This relationship was explored by Wood, Vine, and Wilson [10], whereby participants were required to perform a hand-gun shooting task in a laboratory setting. When anxiety increased due to pressure, participants with lower WM capacity experienced a decline in performance, suggesting that anxiety caused disruptions in attention control by participants with lower WM capacity. Similar results were evident in intermediately skilled tennis players when playing competitive tennis matches [11]. WM capacity was positively associated with winning decisive sets during matches. It was assumed that decisive sets evoked the most pressure during a match. If taken at face value, this study provides evidence that the laboratory findings of Wood et al. [10] may be generalizable. However, the difficulty in establishing whether a decisive set did actually evoke greater pressure limits the strength of the conclusions that can be drawn. Certainly, the assessment of performance based on the outcome of sets is not likely to capture the point-by-point pressure that occurs during a match (i.e., during a break point).

Performing poorly under pressure also manifests when performers attempt to consciously control their movements (*conscious processing hypothesis* [12]; *explicit monitoring hypothesis*, [13]). This is commonly referred to as “reinvesting” (i.e., the theory of reinvestment, [14]). Individuals more prone to reinvestment typically perform less well in pressure situations [15]. This is because reinvestment requires WM, and WM capacity reduces when anxiety increases as a result of pressure [16, 17, 18]. Conflicting correlations have been reported between a person’s predisposition for reinvesting (as measured by scores on a questionnaire) and WM capacity. For example, Laborde et al. [17] revealed a negative correlation between scores on the Decision Specific Reinvestment Scale [19] and WM capacity, but only when WM capacity was assessed under pressure. Hence, participants who experienced a greater decline in WM capacity when pressure was heightened were also more likely to reinvest (or vice versa). Buszard, Farrow, Zhu, and Masters [20], however, found the opposite relationship, with scores on the Movement Specific Reinvestment Scale [21] positively related to WM capacity (although it was not measured under pressure). Clearly, more research is required to understand these interactions between WM capacity, reinvestment and performance under pressure.

Tactical decision making

It is clear that WM capacity does influence decision making skill, but only in specific situations. These include (a) when decisions are to be made in the face of distracting stimuli and (b) when a coach provides instructions that should be ignored [22]. With regards to the former, semi-professional basketball players were presented with static images of match situations and were asked to decide whether to pass or shoot the ball. The task was completed in two conditions, one with and one without distracting auditory message. Results revealed that participants with lower WM capacity were less capable of inhibiting the distracting auditory message and, consequently, made more incorrect decisions in this condition.

Larger WM capacity also appears to facilitate the ability to resolve conflict between a coach's instructions and what the correct decision should be for a given decision making situation [22]. Semi-professional ice-hockey players with lower WM capacity tended to follow the coach's instruction regardless of the situation. Comparatively, players with larger WM capacity were better able to resolve conflict between the instructions and the situation and, consequently, made the correct decision more often. Whilst these well-controlled experiments demonstrate that WM capacity can influence decision making in sport, the use of static images currently limits generalizability to naturalistic settings (e.g., [23, 24]). Future research needs to replicate these findings while using more representative stimuli.

Motor skill acquisition

Practice can encourage performers to consciously attend to their movements [12]. This typically occurs when errors are made or when a coach provides instructions about movement patterns. Consciously attending to movements is often associated with hypothesis testing behaviour (involving WM) whereby the performer attempts to consciously problem solve how to execute the skill more effectively. Researchers have consequently suggested that a style of practice that draws heavily upon WM might disadvantage individuals with low WM capacity [25, 26, 27]. Research examining populations that typically possess low or underdeveloped WM capacity, such as children and older adults, provide support for this hypothesis [28, 29, 30]. In these studies, participants' displayed greater improvements when demands on WM were reduced by minimising errors during practice (i.e., errorless practice).

Many studies reveal associations between WM capacity and acquisition of simple motor skills, such as, finger tapping tasks [31, 32, 33, 34, 35, 36] and joystick tasks [37, 38]. These studies suggest that WM capacity influences error-detection-and-correction processes and motor sequence learning (for reviews, see [5, 39, 40]). It is unclear, however, whether these correlations are also apparent in more complex motor skills. In a rare study of WM capacity and complex motor skill acquisition, Brocken, Kal and van der Kamp [41] examined the relationship between WM capacity and performance change over a period of practice on a golf putting task. The study specifically compared the difference between two different types of instructions – an internal instruction, whereby attention was directed towards the movements, and an external instruction, whereby attention was directed away from the movements. Participants included novice children aged 8-9 years and 11-12 years. WM capacity was hypothesised to influence performance change when internal instructions were provided, as internal instructions were thought to cause participants to consciously control their movements (therefore utilising WM). The hypothesis was not supported, however, as no significant correlations were found between WM capacity and performance change over practice following either instruction. It is possible that the instructions did not impose large enough demands on WM. Indeed, the instructions were in the form of an analogy, and analogies reduce demands on WM [42]. More research is required to understand *if* and *when* WM capacity is influential when learning complex motor skills.

Studies examining skill performance (as opposed to acquisition) have found correlations between WM capacity and cortical activity in regions of the brain associated with implicit and explicit learning. Performance on a verbal WM capacity task was positively associated with electroencephalography (EEG) activity in the regions of the cortex linked with explicit learning (i.e., engaging verbal processes) during a tennis hitting task [43]. Conversely, performance on a visuo-spatial WM capacity task was negatively associated with EEG activity in these regions. Hence, WM capacity might predispose individuals to have a preference for implicit or explicit motor learning. These findings provide an interesting future direction for translational research to consider.

Sport expertise

Early accounts of expertise considered long term WM – an additional construct to the standard WM model – as a variable that explained expert performance [44]. Long term WM was proposed to explain how skilled performers bypass limitations of WM capacity. For instance, an expert basketball player can recall information about the position of players on a court in more detail and more accurately compared to a novice player. Significantly, the amount of information recalled typically exceeds capacity limitations of WM; hence, this information was thought to be stored in a skill-specific long-term WM. However the long-term WM theory has proven difficult to test, which limits advancements of the theory [45].

With regards to WM capacity, there is no evidence that a larger capacity facilitates the attainment of sport expertise. Furley and Wood [7] retrospectively analysed data to show semi-professional basketball players and semi-professional ice hockey players did not possess greater WM capacity than the average person (or non-experts). Similarly, skilled basketball players did not perform better than a cohort of participants who had not played team-ball sports on a WM task [6]. Nonetheless, given that WM capacity seems to influence some skills in sport, it may be considered to be a potential limiting factor in sports performance in specific contexts. Future research comparing experts with non-experts on measures of WM capacity may differentiate between certain types of players in sport. For example, it may be that some players draw more heavily upon WM due the position that they play and the subsequent situations that they encounter. Hence, experts in these particular positions might display a larger WM capacity compared to non-experts in the same position.

Interestingly, the relationship appears to be reciprocal, with WM capacity improving as a result of engaging in sport that demands WM involvement (e.g., wrestling training; [46]; for reviews, see [47, 48]). Likewise, it was recently hypothesised that a culture of striving for success might train athletes to control attention in the face of distractions; thereby improving the ability to use WM capacity [49]. A systematic approach is required to understand the reciprocal relationship between WM capacity and sport skills, and to understand how WM capacity might influence sport expertise.

Conclusion

WM capacity appears to influence several skills and contexts integral to sport. Larger WM capacity was associated with better performance under pressure in a laboratory setting and, less conclusively, in a naturalistic setting. WM capacity was also associated with decision making performance when distractions were present or when the coach provided invalid instructions. However, these experiments need to be replicated in settings with greater ecological validity. Finally, WM capacity appears to influence skill acquisition when performing simple skills, but there is no evidence to suggest that WM capacity influences the acquisition of complex skills. This is likely due, however, to the limited focus on complex motor skills. Certainly, there is evidence that WM capacity is related to cortical activity when performing a complex motor skill, which provides impetus for studies investigating the acquisition of a motor skill. Most of the research implicating WM capacity as an influential variable is based on correlations, or extreme group comparisons (high vs. low WM capacity). To truly understand whether WM capacity affects sport skills, experimental designs need to focus on the causal relationship. Whilst WM capacity does not appear to be a vital characteristic of sport expertise, it is likely to either facilitate or hinder the development of expertise and performance in certain contexts. Understanding what these contexts are should be beneficial for practitioners working in sport.

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