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Attention, working-memory control, working-memory capacity, and sport performance: The moderating role of athletic expertise

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Abstract

The aim of this research was to detangle the association between attention, working-memory (focusing on both control and capacity functions), and sport performance across athletic expertise. Specifically, the mediating effect of working-memory-control and working-memory-capacity on the attention and performance relationship will be investigated, and whether this effect differs across athlete expertise. A sample of 359 athletes (M_{age} = 18.91 ± *SD* = 1.01; 54.87% male) with a range of athletic expertise (novice n = 99, amateur n = 92, elite n = 87, and super-elite n = 81) completed a battery of neurocognitive tasks assessing attention, working-memory-control, working-memory-capacity, and a cognitively engaging motor task (e.g., basketball free-throw task). Athletes with more expertise performed better on tasks of attention, working-memory-control and working-memory-capacity. Results of structural equation modelling indicated a positive association between the cognitive measures and sport performance. Specifically, working-memory-control and working-memory-capacity mediated the attention and sport performance relationship. Additionally, invariance testing indicated larger effects for those with more athletic expertise. These findings provide a better understanding of how attention and the control and capacity functions of working-memory interact to predict performance. Theoretical and practical implications of these results are discussed.

Key Words: *Attention; Working-Memory; Working-Memory Capacity; Athlete Performance; Athlete Expertise*.

Introduction

Research postulates that elite athletes possess more efficient cognitive processing compared to their less elite counterparts (Swann, Moran, & Piggott, 2015; Vaughan, Laborde, & McConville, 2019; Vestberg et al., 2017; Voss, Kramer, Basak, Prakash, & Roberts, 2010). However, understanding the cognitive mechanics behind performance is difficult given the amount of task and situational stimuli involved in the dynamic and complex sport environment (Voss et al., 2010). An athletes' attention, defined as the allocation of cognitive resources to internal or external stimuli, is key to successful performance (see Furley & Wood, 2016, for a review of attention and working-memory in sport). Whilst attention is dependent on an individual's goal, and the number of stimuli processed, it also relies on the optimal manipulation of this information (i.e., working-memory; Furley & Wood, 2016). Therefore, it could stand to reason that athletes with superior working-memory (control and capacity functions, see Baddeley, 2003) may be better equipped to deal with the attentional challenges of competitive sport (e.g., managing task relevant and irrelevant stimuli). This paper investigates the mediating effect of working-memory-control and working-memory-capacity on the attention-performance relationship, and whether this differs across athlete expertise.

Attention, Working-Memory-Control, and Working-Memory-Capacity

Research has attested to the importance of higher-order cognitive processes such as attention and working-memory to sport performance (Furley & Wood, 2016; Vestberg et al., 2017). Working-memory (i.e., ability to store and mentally manipulate information) is a central component of executive function and may have governance over shifting (i.e., ability to move attention) and inhibition (i.e., ability to withhold a dominant response; see Miyake et al., 2000) according to attentional-control-theory (i.e., coordination of attentional resources; Eysenck, Derakshan, Santos, & Calvo, 2007).

Two main aspects of working-memory should be distinguished (see Baddeley, 2003); working-memory-control and working-memory-capacity. Working-memory-control refers to the manipulation of information as described by the central-executive responsible for processes such as updating (e.g., manipulating incoming information and replacing old information; Miyake et al., 2000), while working-memory-capacity refers to the storage of information whilst in transit (e.g., the amount of information that can be handled as described by the episodic buffer; Engle, 2002). Moreover, working-memory-capacity, as a proxy of the episodic buffer, has been used as a measure of controlled attention (Furley & Memmert, 2012). Whilst sport performance will be somewhat determined by the executive control function (e.g., responsible for coding the most relevant information; Vestberg et al., 2017), the capacity component is also important (e.g., facilitates amount of information possible for processing; Furley & Wood, 2016).

Research suggests a positive relationship between sport-based performance tasks and working-memory-capacity (i.e., greater working-memory-capacity is positively related to sport performance; Wood, Vine, & Wilson, 2016). For example, Buszard, Farrow, Zhu, and Masters (2016) reported that larger verbal-working-memory-capacity is associated with a greater tendency to use explicit processes during a novel tennis hitting task, whereas larger visuo-spatial-working-memory-capacity is associated more with implicit processes. It should be noted that other research reports no effect of working-memory-capacity (Furley & Memmert, 2010). This suggests a more complex relationship and perhaps working-memory-capacity may be associated with performance in some sport situations but not others. Moreover, review work has suggested that the working-memory-capacity and sport performance relationship may be indirect and have called for researchers to further explore the relationship focusing on more explanatory work using more ecologically valid tasks (Buszard & Masters, 2018; Buszard, Masters, & Farrow, 2017). To date, research has failed to adequately distinguish between the components of working-memory. For example, much work fails to discriminate between capacity and control aspects together or uses the terms somewhat interchangeably, adding to confusion in the area. Research has yet to examine these processes concurrently in sport.

Attention has been studied in varying forms such as selective attention (i.e., filtering of stimulus and suppression of distractors) or sustained attention (i.e., maintaining attention on a particular stimulus; Memmert, 2009). However, some of these have considerable overlap with existing constructs such as concentration (e.g., sustained attention; Yogev-Seligmann, Hausdorff, & Giladi, 2008). This research focuses on multiple aspects of attention (i.e., adapting attentional resources via greater visual search sensitivity and ability to ignore distractor patterns) as they have relevance for sport performance and an existing relationship with working-memory (Ku, 2018). Previous research reveals functional overlap between these systems and indicates that working-memory-control, working-memory-capacity, and attention are positively and reciprocally related (Awh, Vogel, & Oh, 2006).

Dual-process theories suggests that attention is governed by automatic and controlled processing (Evans & Stanovich, 2013). For example, the default-interventionist model specifies Type-1, autonomous, and Type-2, controlled, processing. Type-1 processing does not require working-memory as it is automatically activated by relevant stimuli, whereas Type-2 processing requires controlled thinking thus involving working-memory-control and working-memory-capacity (Evans & Stanovich, 2013). This model is theoretically relevant for sport as it is characterised by series of simple and complex activities requiring different degrees of automated and controlled processing (Furley & Wood, 2016; Furley, Schweizer, & Bertrams 2015). Furley et al. (2015) suggest that dual-process theories provide a sound theoretical basis for sport psychology research. However, dual processes may be limited in application. For example, the theory is restricted to a dichotomy in thinking systems which assumes consistency regarding automatic and controlled thinking whilst largely neglecting individual differences (e.g., motivation, cognitive ability, or experience; Evans & Stanovich, 2013). Moreover, much of this work fails to account for a basic objective measure of attention – which is addressed in the current study.

Moreover, most of the previous research lacks real world application regarding their outcome variable, particularly in sport (e.g., non-contextualised measures of performance; for an exception see Buszard et al., 2016). For example, in an attempt to differentiate Type-1 and Type-2 processing, Laurin and Finez (2019) reported a positive relationship between working-memory-capacity and motor performance (ball juggling) when the cognitive load was low (i.e., automated) and a negative relationship when cognitive load was high (i.e., controlled). The dual task of ball juggling and mental arithmetic, although valid in a research context, will have limited application in sport, in that these processes will very rarely be completely binary. For example, passing sequences in soccer are not comprised of only low and high load actions. Additionally, the dual task paradigm is not entirely representative of Type-1 and Type-2 processing in that it assumes the automaticity of one task and negates important individual differences (e.g., expertise; Laurin & Finez, 2019; Swann et al., 2015). Moreover, based on the literature and Baddeley’s (2003) recommendation, working-memory-control and working-memory-capacity may be more suitably applied as a mediator in the attention-performance relationship (Buszard & Masters, 2018; Buszard et al., 2017; Furley & Memmert, 2012; Furley & Wood, 2016).

Athletic Expertise and Performance on Attention and Working-Memory

Research findings regarding the influence of athletic expertise on attention, working-memory-control and working-memory-capacity is equivocal (Furley & Wood, 2016). Whilst some research suggests that experts, at least from sport, do not score significantly higher on measures of working-memory-control and working-memory-capacity (Buszard & Masters, 2018; Buszard et al., 2017; Furley & Wood, 2016), other research suggests that working-memory-control differs across athlete expertise (Vestberg et al., 2017). Moreover, experimental work with athletes attests to the importance of working-memory-capacity in tactical decision-making in professional and semi-professional athletes which is reliant on controlled attention (Furley & Memmert, 2012). However, the researchers did not differentiate their findings across expertise, limiting understanding. Additionally, and key to the current study, much research combines working-memory-control and working-memory-capacity together, possibly masking effects associated with these unique processes. Inconsistencies in the literature may be due to methodological differences, such as, no consistent framework of athlete expertise (Swann et al., 2015), or a failure to objectively measure attention (e.g., Laurin & Finez, 2019).

To our knowledge, no study has directly tested attention, working-memory-control, and working-memory-capacity using neurocognitive measures, thus limiting understanding of the interplay between these complex cognitive processes. Considering prior work and theory (e.g., building-block-hypothesis; Hambrick, Macnamara, Campitelli, Ullénjj, & Mosingjj, 2016) suggesting that expertise is comprised of domain-general and domain-specific factors, it is likely that those with more expertise, who score higher on attention, working-memory-control and working-memory-capacity, may also perform better in sport tasks.

The Current Study

In sum research reports mixed conclusions regarding the interplay between attention, working-memory-control, working-memory-capacity and sport performance across athletic expertise. However, reconciliation of findings is difficult due to inconsistencies and limitation in methodologies, and underpowered analyses trivialising effects. Previous work is yet to provide a cognitive measure of attention using multiple measures to capture the complexity of this process (i.e., adapting attentional resources via greater visual search sensitivity and ability to ignore distractor patterns), and examine the individual functions of working-memory-control and working-memory-capacity. Also, research is yet to provide a direct test of models against different levels of athletic expertise.

Review work outside of sport suggests a positive relationship between higher-order cognitive processes such as attention and higher working-memory (Ku, 2018; Yogev-Seligmann et al., 2008). Therefore, a cognitively engaging motor activity (e.g., basketball free-throw task; Stoll, Lau & Stoeber, 2008) is expected to place concurrent demands on attention, working-memory-control and working-memory-capacity, requiring increased cognitive engagement (de Greeff, Bosker, Oosterlaan, Visscher, & Hartman, 2018). It is not fully understood whether this premise holds across varying levels of athletic expertise, although given the association between cognitive and athletic expertise (Vaughan et al., 2019), we expect that athletes with more expertise will score higher on those measures than those with less expertise. This research aims to:

1. Determine whether attention, working-memory-control, working-memory-capacity and motor performance differed across athletic expertise.
2. Examine the mediation effect of working-memory-control and working-memory-capacity on the attention-performance relationship, and assessing whether this is moderated by athletic expertise.

Methods

Participants

Participants were 359 English speaking youth athletes from basketball academies in the United Kingdom (M_{age} = 18.91 ± SD = 1.01; 54.87% male). All athletes were regularly involved in training and competition. Participants had 3.3 – 9.7 years of practice from regional to international playing levels. All participation was conducted in accordance with the requirements of the Ethical Committee of Faculty of Education, Hokkaido University.

Participants were classified based on Swann et al.'s (2015) recommendations which resulted in a sample of novice (n = 99), amateur (n = 92), elite (n = 87) and super-elite (n = 81). Monte Carlo simulation for estimation of sample size with no missing data, standard error biases that do not exceed 10%, and coverage of confidence intervals set at 95%, indicated that sufficient power (80%) could be achieved with a sample size of 326 (Muthén & Muthén, 2017).

Materials

The Rapid Visual Information Task (RVP), Match to Sample Visual Search Task (MTS), Spatial Span Task (SSP) and Spatial Working-Memory Test (SWM) from the Cambridge Neuropsychological Test Automated Battery (CANTAB, Cambridge Cognition Ltd) was utilised to assess attention, working-memory-control and working-memory-capacity respectively. The CANTAB has been reported as a robust measure of cognition in and out of sport supporting its reliability and validity as distinct measures of sustained visual attention, visual search, working-memory-control, and working-memory-capacity (Micai, Kavussanu, & Ring, 2015; O'Brien et al., 2017; Syvaoja et al., 2015; Vaughan et al., 2019).

Sustained visual attention was assessed with the RVP. Participants are required to detect patterns of number target sequences (e.g., 2–4–6). A white box shown in the centre of the screen containing digits from 2 to 9 in a random order at a rate of 100 digits per minute. Once the participants see the target sequence, they must respond by using the press pad as quickly as possible. The outcome measure was A′. A′ is the signal detection measure of sensitivity to the target sequence regardless of response tendency. Higher scores indicate better performance.

Visual search with a speed/accuracy trade-off was assessed with the MTS, a measure which assesses the participant's ability to match visual samples. The participant is shown a complex visual pattern in the middle of the screen. After a short delay, a varying number of similar patterns are shown around the edge of the screen increasing along trails. Only one of these patterns matches the previously displayed one. Efficient performance requires the ability to ignore the distractor patterns and to indicate the correct one. The outcome measure is percent correct across all trials. Higher scores indicate better performance.

Working-memory-capacity was assessed with the SSP. The SSP is a computerised version of the Corsi-Blocks-task and measures visuospatial memory span length. In each trial, there are 10 white boxes on the screen, and the colour of a specified number of boxes changes one by one. Participants are required to reproduce the sequence by touching the same boxes in the same order that the boxes changed colour. If the participant reproduces the correct sequence, they move to the next difficulty level, where one more box is added to the sequence. The task starts with a two-box sequence and ends with a nine-box sequence. The outcome measure is span length based on the maximum sequence correctly recalled (i.e., larger sequences indicates higher working-memory-capacity).

Working-Memory-Control was assessed with the SWM. The SWM is a measure of retention and manipulation of visuospatial information. An increasing number of boxes in a random pattern are presented on screen during trials. The participant was instructed to search for tokens, opening the boxes by touching them, and advised not to return to a box that had already yielded a token. As participants move through trials the position of boxes change and increase to become more difficult. The outcome measure was the number of times the participant started a new search by touching a different box. Lower scores suggest that the participant used a predetermined sequence by beginning with a certain box, and when a token was found, he/she returned to that box to start a new search (i.e., lower scores indicate more efficient working-memory-control).

To measure sport performance, the basketball free-throw task (i.e., unopposed shots at the basketball hoop from behind the centre of the free throw line) used by Stoll et al. (2008).

Participants performed 10 series of two shots with a 30-second rest period between each set to simulate the sport-specific conditions of a basketball free-throw. Scoring followed Stoll et al. (2008); three points for scoring without the ball touching the rim, two points for scoring with the ball touching the rim, one point for having the ball hit the rim but not score, and zero points for a shot that missed and did not touch the rim. With this, participants could achieve a score from 0 to 60 points with higher points indicating better performance.

Procedure

Participants were recruited via sports coaches as gatekeepers. The study was approved by the university ethics committee in the United Kingdom. Before participants began, they read information sheets and provided informed consent. Participants completed the cognitive tests first in a counterbalanced order. Testing was completed on a GIGABYTE 7260HMW BN touchscreen computer running a Pro Windows 8 operating system with a high resolution 13-inch display. Participants then completed the basketball task. Testing lasted approximately 40 minutes. Following testing, participants were debriefed and thanked. Data was collated and retrieved from CANTAB and entered onto the SPSSv24 for preliminary analysis.

Design and Analysis

The study adopted a quasi-experimental design with purposive sampling. Only a small number of cases (1.4%) were missing therefore ipsatised item replacement was used (i.e., replaced with the mean; Tabachnick & Fidell, 2007). Box’s M test assessing the variance–covariance matrices of male and female participants was non-significant thus analyses were collapsed across gender. Age did not correlate significantly with the cognitive or performance variables therefore was not entered as a covariate. Multivariate skewness and kurtosis coefficients (Muthén & Muthén, 2017) indicated no departure from normality ($p > .05$).

Descriptive statistics, ANOVA’s testing differences across groups, and zero-order correlations exploring relationships were requested. Regression modelling was used to determine a relationship between the predictors (i.e., RVP & MTS) and outcome variable (i.e., basketball free-throw task).

Structural equation modelling (SEM) with MPlus 7.4 (Muthén & Muthén, 2017) was used to examine the mediating effect of working-memory-control and working-memory-capacity on the attention-performance relationship across novice, amateur, elite, and super-elite athletes. Structural equation modelling is a multivariate statistical analysis technique used to analyse structural relationships (e.g., association between multiple and interrelated factors simultaneously in a single flexible analysis; Byrne, 2012; Muthén & Muthén, 2017). Miyake et al. (2000) and Miyake and Friedman (2012) argue that SEM should be used to model executive function data in order to examine unique and error variances. The analysis was conducted using robust maximum likelihood estimation (Muthén & Muthén, 2017), where a measurement model was constructed utilising latent factors, followed by testing structural relationships. To assess mediation effects (partial and full mediation models), bias-corrected bootstrapping was used. The mean of 1000 estimated indirect effects was calculated by creating 1000 bootstrap samples via random sampling with replacement. If the 95% confidence intervals (CI) of the indirect effect did not include zero, significant mediation effect was inferred.

Multigroup analysis was used to assess whether the mediation model differed across athlete expertise (i.e., moderation). Group differences were explored whereby invariance is tested between the configural model (i.e., the same pattern of factors and loadings across groups), metric model (i.e., invariant loadings), and scalar model (i.e., invariant factor loadings and intercepts). To evaluate model fit, several fit indices in combination with the likelihood ratio statistic e.g., Chi-Square (χ^2) were adopted. A model is deemed acceptable if the Root Mean Square Error of Approximation (RMSEA) with 95% Confidence Intervals (CI) and Standardised Root Mean Residual (SRMR) is .06 or less, and each of the

Comparative Fit Index (CFI) and Tucker Lewis Index (TLI) are .90 or greater (Hu & Bentler, 1999). In order to select the most parsimonious model from the tests of invariance, the Bayes information criterion (BIC) and Akaike's information criterion (AIC) were used. The AIC and BIC assign a greater penalty to model complexity and therefore select more efficient models (Byrne, 2012). Chen (2007) suggests that changes below .01 and .015 in the CFI and RMSEA, respectively, would be supportive of an invariant model in relation to the previous model.

Results

Preliminary Analyses

Descriptive statistics, ANOVA models and zero-order correlations were inspected (see Table 1). First, RVP, MTS, SSP, and performance showed small-to-medium positive correlations, whereas SWM showed small-to-medium negative correlations with the other variables. The medium effects reported coincide with previous work suggesting that executive functions will be somewhat interrelated but independent (Micai et al., 2015; Miyake & Friedman, 2012). Next, ANOVA modelling produced small effect sizes across all variables indicating higher score amongst those with more expertise in comparison to those with less expertise. Finally, multiple regression indicated that RVP ($\beta = .15$, $p < .01$) and MTS ($\beta = .11$, $p < .01$) explained 18% of the sport performance variance ($R^2 = .178$, $p < .01$) supporting the proposed mediation analysis (Baron & Kenny, 1986).

Structural Equation Modelling

A measurement model consisting of the four cognitive measures and performance measure was created (i.e., RVP, MTS, SSP, SWM & Performance; see Figure 1). The results indicated acceptable fir to the data χ^2 (7) = 21.33, $p < .01$, RMSEA = .056 95% (CI = .052–.059), SRMR = .055, TLI = .932, CFI = .921, AIC = 4356.212, BIC = 4471.652. Parameter estimates indicated all direct paths were significant, suggesting that working-memory-control and working-memory-capacity may fully mediate the attention-performance relationship. Specifically, RVP (β = -.12, SE = .08, *p* < .01) and MTS (β = -.09, SE = .04, *p* < .01) was negatively related to SWM, whereas RVP (β = .13, SE = .02, *p* < .01) and MTS (β = .10, SE = .05, *p* < .01) was positively related SSP. The performance link was negative with SWM (β = -.10, SE = .06, *p* < .01), whereas SSP (β = .15, SE = .04, *p* < .01) was positive.

To test mediation, the partial mediation model with the direct paths not constrained against the full mediation model with direct paths constrained to zero were compared. Results indicated the full mediation model was a good fit χ^2 (8) = 24.45, *p* < .01, RMSEA = .056 with 95% CI (.051–.063), SRMR = .052, TLI = .941, CFI = .939, AIC = 4137.667, BIC = 4289.347. The partial mediation model was not a significantly better fit to the data $\Delta\chi^2$ (2) = 1.25, *p* < .01 implying full mediation. The significant mediating effect of working-memory-control and working-memory-capacity indicated that the RVP and MTS exerted indirect effects on performance through the simple mediating effect of SWM and SSP (see Table 2).

Multigroup analyses examined whether the mediation model differed across athlete expertise (i.e., moderation). Comparison of the configural model (e.g., all parameters allowed to be unequal across groups) against the metric model (e.g., holding loadings equal across groups) indicated significantly poorer fit χ^2 (12) = 9.52, *p* < .01 with changes in both ΔRMSEA = .014 and ΔCFI = .019. Comparisons against the scalar model (e.g., constraining factor loadings and intercepts across groups) also produced poorer fit χ^2 (16) = 10.24, *p* < .01 with further changes in both ΔRMSEA = .021 and ΔCFI = .014, thus providing evidence of non-invariance. The configural (AIC = 4227.658 & BIC = 4364.517) model also indicated lower AIC and BIC values in comparison to the metric (AIC = 4375.697 & BIC = 4488.364) and scalar (AIC = 4482.876 & BIC = 4593.931) models. Path coefficients of separate multigroup models highlighted differences in estimates across athlete expertise groups. For example, estimates were in general stronger for the super-elite groups (see Table 3).

Discussion

The aim of this study was twofold; first to determine the interplay between attention via the RVP and MTS tasks, working-memory-control and working-memory-capacity via the SSP and SWM tasks, and a cognitively engaging motor task (i.e., basketball free-throws), and to see whether this differentiated across athletic expertise (Buszard et al., 2016; Buszard et al., 2017; Buszard & Masters, 2018; Furley & Wood, 2016; Swann et al., 2015). Second, to investigate the mediation effect of working-memory-control and working-memory-capacity on the attention-performance relationship, and whether this was moderated by athletic expertise. Regarding the first aim, results supported predictions whereby super-elite athletes performed better on the cognitive and motor measures in comparison to novice athletes (Furley & Memmert, 2010; Vestberg et al., 2017). Further, SEM corroborated previous work (Ku, 2018; Yogev-Seligmann et al., 2008), and indicated that higher attention scores resulted in greater working-memory-capacity (i.e., higher SSP) and working-memory-control (i.e., lower SWM). Regarding the second aim, working-memory-capacity and working-memory-control positively mediated the attention and performance relationship (Furley & Wood, 2016). Moreover, effects from invariance testing were larger for those with more expertise, suggesting that performance was moderated by athletic expertise (Vestberg et al., 2017).

Findings related to the first aim are in line with previous research: attention and working memory measures correlate positively (Ku, 2018), which may be linked to the fact that both activate the prefrontal cortex and anterior cingulate cortex, suggesting similar underlying neural mechanisms (Yogev-Seligmann et al., 2008). The fact these measures are also correlated positively with performance may illustrate the positive association between cognitive and athletic expertise (Vaughan et al., 2019). These findings align to recent research highlighting the importance of working-memory-capacity, suggesting that it may interact with other processes explaining associations with athletic expertise (Buszard et al., 2017; Buszard & Masters, 2018). Moreover, there may be a reciprocal relationship between working-memory-capacity and expertise which results in improved performance (Buszard et al., 2017).

Findings related to the second aim confirm our hypothesis, of working-memory mediating the relationship between attention and performance support predictions. Findings from the mediation model suggest that the influence of attention (i.e., visual search sensitivity and the ability to ignore distractor patterns) on motor performance is determined by working-memory-capacity (i.e., memory span length) and working-memory-control (i.e., ability to manipulate information). This finding supports previous work outside of sport (Ku, 2018; Yogev-Seligmann et al., 2008), but disagrees with previous work in sport regarding the moderating effect of athletic expertise (e.g., no difference across expertise; Furley & Wood, 2016).

There are some possible sport-specific explanations for this. First, basketballers participate in a cognitively demanding sport and this increases in parallel with expertise. The cognitive-engagement-hypothesis stipulates that greater cognitive processing may be associated with increased opportunity to engage in cognitively engaging physical activities (de Greeff, 2018). Second, research posits a cognitive skills transfer when examining the prognostic validity of higher-order cognitions in sport (Vestberg et al., 2017). Whilst there is debate about how far these cognitive skills can transfer between domains, there is consensus suggesting that more complex skills will see greater increases in cognition (Voss et al., 2010). These explanations also provide insight regarding the moderated (e.g., larger) effects in those with more expertise (noted in other research utilising the same expertise framework; Vaughan et al., 2019). For example, Voss et al. (2010) suggest that athletes improve in specific cognitive skills which may manifest in non-sport contexts. It is also logical to assume that these higher-order cognitive processes interact with long-term-memory to facilitate expertise development and performance (Awh et al., 2006). The current research provides a foundation for future work to further investigate this interaction.

Evidence from neuropsychology can further explain this effect. First, the link between attention and working-memory, suggests a sequential relationship in that attention is responsible for encoding and working-memory is responsible for maintenance in task performance (i.e., attention is the processing gatekeeper and working-memory the bridge with performance; Awh et al., 2006). Moreover, rarely are both systems employed unilaterally. It is possible that both systems may have partial dependence from each other. According to perceptual-load-theory (Lavie, 1995), attentional uptake is continuous, encoding both early and late stimuli. Whilst the processing of relevant and irrelevant stimuli is situated within working-memory, additional information may be required from attention for successful performance (Lavie, 1995). Higher expertise in the basketball free-throw task may also align to theories proposing attention-based rehearsal in working-memory (Awh et al., 2006). That is, maintenance of spatial information in working-memory is accomplished through a sustained shift of spatial attention to a memorised location, which may be advantageous to experts (Awh et al., 2006; Swann et al., 2015).

Limitations and Future Directions

The present study has several strengths, such as use of SEM with a large sample, and standardised framework of expertise. There are however some limitations which should be addressed in future work. For example, the cross-sectional design limits causality and direction, and using single measures provides only a snapshot of ability. Moreover, designs that determine causality and direction should be adopted (e.g., longitudinal). Future work should endeavour to include multiple measures of working-memory-control and working-memory-capacity to examine consistency across tasks. Likewise, although attempts were made to increase the ecological application of the model, the methodology was heavily focused upon visual processes and auditory/phonological processes may also play an important role (Baddeley, 2003). Further, other variables may explain the effects reported. For example, the transference of cognitive skills may not be due to sport participation but other cognitively engaging activities such as playing video games. One important confounding variable in the area of cognitive sport psychology is physical activity/fitness (Hertzog, Kramer, Wilson, & Lindenberger, 2008; Hillman, Khan, & Kao, 2015). For example, enhanced cognitive function may be a result 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 (Hillman, Erickson, & Kramer, 2008). Whilst increases in athletic expertise should coincide with increases in physical fitness (e.g., professionalism towards sport, Swann et al., 2015), we did not control for this important factor. Future research should control for physical fitness/activity or include high-fit age-matched groups for comparison (Hertzog et al., 2008; Hillman et al., 2008; 2015).

Although the current work used a cognitively engaging measure of motor performance, future work could extend these findings by providing a test of different cognitive load levels, similar to previous research (e.g., Laurin & Finez, 2019), and a direct test of attentional-control-theory (Eysenck et al., 2007) by manipulating pressure scenarios to examine the model’s efficacy with regards to choking (Hill, Hanton, Matthews & Fleming, 2010) building on the work of Wood and colleagues (2016). We also recommend examining whether training both attention and working-memory helps to cope with the negative effects of pressure (Ducrocq, Wilson, Smith, & Derakshan, 2017). Also, inclusion of the athletic expertise framework utilised may reveal important individual differences in how athletes process anxiety in relation to their cognitive processes. Finally, whilst the basketball free throw task taps attention and working-memory concurrently, it may not place sufficient demands on working-memory-control or working-memory-capacity and a more complex task involving elements of in-situ decision-making or performing under pressure would provide greater insight into these processes. Testing the model in this respect in future work would increase its application for researchers and practitioners.

Conclusion

The current study is the first to investigate the interplay between neurocognitive measures of attention, working-memory-control and working-memory-capacity, and a cognitively engaging motor task across athletic expertise. Results indicated working-memory-control and working-memory-capacity mediated the attention and performance relationship and that these effects were moderated (i.e., larger) for those with more athletic expertise. These findings extend our understanding of the attention and working-memory association by objectively capturing attention, using working-memory-control and working-memory-capacity as mediators, as proposed by Baddeley's (2003) model, in sport. Moreover, they provide support for previous work while highlighting the need for more research examining the cognitive processing of athletes (Vaughan et al., 2019). Specifically, future research should investigate how these higher-order processes interact to predict performance. Understanding this relationship may help to design sport-specific training programs targeting them in order to improve performance.

References

Awh, E., Vogel, E. K., & Oh, S. H. (2006). Interactions between attention and working memory. *Neuroscience, 139*(1), 201-208.

Baddeley, A. D. (2003). Working memory: Looking back and looking forward. *Nature Reviews: Neuroscience*, *4*, 829–839.

Baron, R. M., & Kenny, D. A. (1986). The moderator–mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *Journal of Personality and Social Psychology, 51*, 1173–1182.

Buszard, T., Farrow, D., Zhu, F. F., & Masters, R. S. (2016). The relationship between working memory capacity and cortical activity during performance of a novel motor task. *Psychology of Sport and Exercise, 22*, 247-254.

Buszard, T., Masters, R. S., & Farrow, D. (2017). The generalizability of working-memory capacity in the sport domain. *Current Opinion in Psychology*, *16*, 54-57.

Buszard, T., & Masters, R. S. (2018). Adapting, correcting and sequencing movements: does working-memory capacity play a role?. *International Review of Sport and Exercise Psychology*, *11*(1), 258-278.

Byrne, B. M. (2012). *Structural Equation Modeling with Mplus: Basic Concepts, Applications, and Programming*. New York: Routledge, Taylor & Francis Group.

Chen, F. F. (2007). Sensitivity of goodness of fit indices to lack of measurement invariance. *Structural Equation Modeling, 14*, 464–504.

de Greeff, J. W., Bosker, R. J., Oosterlaan, J., Visscher, C., & Hartman, E. (2018). Effects of physical activity on executive functions, attention and academic performance in preadolescent children: a meta-analysis. *Journal of Science and Medicine in Sport, 21*(5), 501-507.

Ducrocq, E., Wilson, M., Smith, T. J., & Derakshan, N. (2017). Adaptive working memory training reduces the negative impact of anxiety on competitive motor performance. *Journal of Sport and Exercise Psychology, 39*(6), 412-422.

Engle, R. W. (2002). Working memory capacity as executive attention. *Current Directions in Psychological Science, 11*, 19–23.

Evans, J. St. B. T., & Stanovich, K. E. (2013). Dual-process theories of higher cognition: Advancing the debate. *Perspectives on Psychological Science*, *8*, 223–241.

Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: Attentional control theory. *Emotion, 7*(2), 336–353.

Furley, P., & Memmert, D. (2010). Differences in spatial working memory as a function of team sports expertise: the Corsi Block-tapping task in sport psychological assessment. *Perceptual and Motor Skills, 110*(3), 801-808.

Furley, P. A., & Memmert, D. (2012). Working memory capacity as controlled attention in tactical decision making. *Journal of Sport and Exercise Psychology, 34*(3), 322-344.

Furley, P., Schweizer, G., & Bertrams, A. (2015). The two modes of an athlete: dual-process theories in the field of sport. *International Review of Sport and Exercise Psychology, 8*(1), 106-124.

Furley, P., & Wood, G. (2016). Working memory, attentional control, and expertise in sports: A review of current literature and directions for future research. *Journal of Applied Research in Memory and Cognition*, 5, 415-425.

Hambrick, D. Z., Macnamara, B. N., Campitelli, G., Ullénjj, F., &Mosingjj, M. A. (2016). Beyond born versus made: A new look at expertise. *Psychology of Learning and Motivation, 64*, 1–55.

Hertzog, C., Kramer, A. F., Wilson, R. S., & Lindenberger, U. (2008). Enrichment effects on adult cognitive development: can the functional capacity of older adults be preserved and enhanced?. *Psychological Science in the Public Interest, 9*(1), 1-65.

Hill, D. M., Hanton, S., Matthews, N. & Fleming, S. (2010). Choking in sport: A review. *International Review of Sport and Exercise Psychology, 3*, 24–39.

Hillman, C. H., Erickson, K. I., & Kramer, A. F. (2008). Be smart, exercise your heart: exercise effects on brain and cognition. *Nature Reviews Neuroscience, 9*(1), 58-65.

Hillman, C. H., Khan, N. A., & Kao, S. C. (2015). The relationship of health behaviors to childhood cognition and brain health. *Annals of Nutrition and Metabolism, 66*(3), 1-4.

Hu, L. T., & Bentler, P. M. (1999). Cut off criteria for fit indexes in covariance structural analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary Journal*, 6, 1–55.

Ku, Y. (2018). Selective attention on representations in working memory: cognitive and neural mechanisms. *PeerJ, 6*, e4585.

Lavie, N. (1995). Perceptual load as a necessary condition for selective attention. *Journal of Experimental Psychology: Human Perception and Performance, 21*(3), 451.

Laurin, R. & Finez, L. (2019). Working memory capacity does not always promote dual-task motor performance: The case of juggling in soccer. *Scandinavian Journal of Psychology*. DOI:10.1111/sjop.12589

Memmert, D. (2009). Pay attention! A review of visual attentional expertise in sport. *International Review of Sport and Exercise Psychology, 2*(2), 119-138.

Micai, M., Kavussanu, M., & Ring, C. (2015). Executive function is associated with antisocial behavior and aggression in athletes. *Journal of Sport and Exercise Psychology, 37*(5), 469-476.

Miyake, A., & Friedman, N. P. (2012). The nature and organization of individual differences in executive functions: Four general conclusions. *Current Directions in Psychological Science, 21*(1), 8-14.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. (2000). The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: A latent variable analysis. *Cognitive Psychology, 41*, 49–100.

O'Brien, J. T., Gallagher, P., Stow, D., Hammerla, N., Ploetz, T., Firbank, M., ... & Ferrier, I. N. (2017). A study of wrist-worn activity measurement as a potential real-world biomarker for late-life depression. *Psychological Medicine, 47*(1), 93-102.

Muthen, L. K., & Muthen, B. O. (2017). *Mplus user's guide (7th ed.)*. Los Angeles: Muthen & Muthen.

Swann, C., Moran, A., & Piggott, D. (2015). Defining elite athletes: Issues in the study of expert performance in sport psychology. *Psychology of Sport and Exercise 16*(1), 3–14.

Stoll, O., Lau, A., & Stoeber, J. (2008). Perfectionism and performance in a new basketball training task: Does striving for perfection enhance or undermine performance? *Psychology of Sport and Exercise, 9*, 620–629.

Syvaoja, H. J., Tammelin, T. H., Ahonen, T., Rasanen, P., Tolvanen, A., Kankaanpaa, A., & Kantomaa, M. T. (2015). Internal consistency and stability of the CANTAB neuropsychological test battery in children. *Psychological Assessment, 27*(2), 698–709.

Vaughan, R., Laborde, S., & McConville, C. (2019). The effect of athletic expertise and trait emotional intelligence on decision-making. *European Journal of Sport Science, 19*(2), 225-233.

Vestberg, T., Reinebo, G., Maurex, L., Ingvar, M., Petrovic, P., & Ardigò, L. P. (2017). Core executive functions are associated with success in young elite soccer players. *PLoS ONE, 12*(2), e0170845.

Voss, M. W., Kramer, A. F., Basak, C., Prakash, R. S., & Roberts, B. (2010). Are expert athletes 'expert' in the cognitive laboratory? A meta-analytic review of cognition and sport expertise. *Applied Cognitive Psychology, 24*, 812–826.

Wood, G., Vine, S. J., & Wilson, M. R. (2016). Working memory capacity, controlled attention and aiming performance under pressure. *Psychological Research, 80*(4), 510-517.

Yogev-Seligmann, G., Hausdorff, J. M., & Giladi, N. (2008). The role of executive function and attention in gait. *Movement Disorders, 23*(3), 329-342.

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Table 1

Descriptive statistics & zero-order correlations

Measure	M (SD)						Zero-order Correlations			
	Total	Super-elite	Elite	Amateur	Novice	ηp^2	1	2	3	4
1. RVP	.91 (.08)	.98 (.04)	.94 (.06)	.88 (.05)	.85 (.07)	.04*				
2. MTS	91.23 (6.35)	97.85 (4.88)	93.57 (5.21)	87.69 (5.63)	84.71 (6.11)	.06*	.41**			
3. SSP	.67 (1.39)	.81 (1.05)	.73 (1.13)	.66 (1.41)	.61 (1.44)	.05*	.25**	.22**		
4. SWM	25.45 (6.78)	19.22 (4.61)	22.87 (4.82)	25.74 (5.39)	27.12 (6.02)	.07**	-.27**	-21**	-.38**	
5. Performance	39.88 (7.18)	53.67 (6.37)	47.31 (6.28)	39.45 (6.88)	34.15 (6.94)	.11**	.17**	.15**	.23**	-.14**

Note. N = 359. RVP = Rapid Visual Information, MTS = Match to Sample Visual Search, SSP = Spatial Span Task & SWM = Spatial Working-Memory, Performance = Basketball Free-Throws.

* $p < .05$ ** $p < .01$

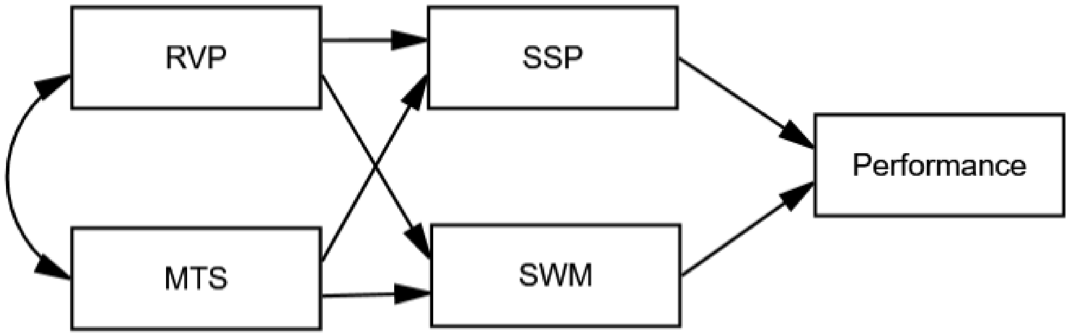

Figure 1. Hypothesised mediation model of working-memory control and working-memory capacity on the attention and performance relationship.

Table 2

Bootstrapping indirect effects & 95% confidence intervals (CI) for the final mediation model.

Model Pathway	Estimate	95% Confidence Interval	
		Lower	Upper
RVP → SWM → Performance	.203	.184	.225
RVP → SSP → Performance	.245	.221	.267
MTS → SWM → Performance	.176	.153	.198
MTS → SSP → Performance	.212	.192	.231

Note. RVP = Rapid Visual Information, MTS = Match to Sample Visual Search, SSP = Spatial Span Task & SWM = Spatial Working-Memory, Performance = Basketball Free-Throws. Pathway significant if confidence interval does not cross zero.

Table 3

Parameter Estimates of invariance models across super-elite, elite, amateur & novice athletes

Path	Total Sample		Super-elite		Elite		Amateur		Novice	
	β	SE	β	SE	β	SE	β	SE	β	SE
RVP → SWM	-.12**	.08	-.17**	.05	-.14**	.06	-.11**	.07	-.10**	.07
RVP → SSP	.13**	.02	.18**	.04	.14**	.03	.10**	.06	.09**	.05
MTS → SWM	-.09**	.04	-.14**	.08	-.12**	.05	-.08**	.03	.07**	.04
MTS → SSP	.10**	.05	.13**	.06	.11**	.04	.09**	.06	.06**	.02
SWM → Performance	-.10**	.06	-.15**	.03	-.12**	.03	.08**	.05	.07**	.04
SSP → Performance	.15**	.04	.19**	.07	.16**	.08	.12**	.06	.10**	.05

Note. RVP = Rapid Visual Information, MTS = Match to Sample Visual Search, SSP = Spatial Span Task & SWM = Spatial Working-Memory, Performance = Basketball Free-Throws. * p < .05 ** p < .01