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

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18 **Abstract**

19 The aim of this research was to detangle the association between attention, working-memory
20 (focusing on both control and capacity functions), and sport performance across athletic
21 expertise. Specifically, the mediating effect of working-memory-control and working-
22 memory-capacity on the attention and performance relationship will be investigated, and
23 whether this effect differs across athlete expertise. A sample of 359 athletes ($M_{age} = 18.91 \pm$
24 $SD = 1.01$; 54.87% male) with a range of athletic expertise (novice $n = 99$, amateur $n = 92$,
25 elite $n = 87$, and super-elite $n = 81$) completed a battery of neurocognitive tasks assessing
26 attention, working-memory-control, working-memory-capacity, and a cognitively engaging

1 motor task (e.g., basketball free-throw task). Athletes with more expertise performed better
2 on tasks of attention, working-memory-control and working-memory-capacity. Results of
3 structural equation modelling indicated a positive association between the cognitive measures
4 and sport performance. Specifically, working-memory-control and working-memory-capacity
5 mediated the attention and sport performance relationship. Additionally, invariance testing
6 indicated larger effects for those with more athletic expertise. These findings provide a better
7 understanding of how attention and the control and capacity functions of working-memory
8 interact to predict performance. Theoretical and practical implications of these results are
9 discussed.

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

1 **Introduction**

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

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

19 Research has attested to the importance of higher-order cognitive processes such as
20 attention and working-memory to sport performance (Furley & Wood, 2016; Vestberg et al.,
21 2017). Working-memory (i.e., ability to store and mentally manipulate information) is a
22 central component of executive function and may have governance over shifting (i.e., ability
23 to move attention) and inhibition (i.e., ability to withhold a dominant response; see Miyake et
24 al., 2000) according to attentional-control-theory (i.e., coordination of attentional resources;
25 Eysenck, Derakshan, Santos, & Calvo, 2007).

1 Two main aspects of working-memory should be distinguished (see Baddeley, 2003);
2 working-memory-control and working-memory-capacity. Working-memory-control refers to
3 the manipulation of information as described by the central-executive responsible for
4 processes such as updating (e.g., manipulating incoming information and replacing old
5 information; Miyake et al., 2000), while working-memory-capacity refers to the storage of
6 information whilst in transit (e.g., the amount of information that can be handled as described
7 by the episodic buffer; Engle, 2002). Moreover, working-memory-capacity, as a proxy of the
8 episodic buffer, has been used as a measure of controlled attention (Furley & Memmert,
9 2012). Whilst sport performance will be somewhat determined by the executive control
10 function (e.g., responsible for coding the most relevant information; Vestberg et al., 2017),
11 the capacity component is also important (e.g., facilitates amount of information possible for
12 processing; Furley & Wood, 2016).

13 Research suggests a positive relationship between sport-based performance tasks and
14 working-memory-capacity (i.e., greater working-memory-capacity is positively related to
15 sport performance; Wood, Vine, & Wilson, 2016). For example, Buszard, Farrow, Zhu, and
16 Masters (2016) reported that larger verbal-working-memory-capacity is associated with a
17 greater tendency to use explicit processes during a novel tennis hitting task, whereas larger
18 visuo-spatial-working-memory-capacity is associated more with implicit processes. It should
19 be noted that other research reports no effect of working-memory-capacity (Furley &
20 Memmert, 2010). This suggests a more complex relationship and perhaps working-memory-
21 capacity may be associated with performance in some sport situations but not others.
22 Moreover, review work has suggested that the working-memory-capacity and sport
23 performance relationship may be indirect and have called for researchers to further explore
24 the relationship focusing on more explanatory work using more ecologically valid tasks
25 (Buszard & Masters, 2018; Buszard, Masters, & Farrow, 2017). To date, research has failed

1 to adequately distinguish between the components of working-memory. For example, much
2 work fails to discriminate between capacity and control aspects together or uses the terms
3 somewhat interchangeably, adding to confusion in the area. Research has yet to examine
4 these processes concurrently in sport.

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

15 Dual-process theories suggests that attention is governed by automatic and controlled
16 processing (Evans & Stanovich, 2013). For example, the default-interventionist model
17 specifies Type-1, autonomous, and Type-2, controlled, processing. Type-1 processing does
18 not require working-memory as it is automatically activated by relevant stimuli, whereas
19 Type-2 processing requires controlled thinking thus involving working-memory-control and
20 working-memory-capacity (Evans & Stanovich, 2013). This model is theoretically relevant
21 for sport as it is characterised by series of simple and complex activities requiring different
22 degrees of automated and controlled processing (Furley & Wood, 2016; Furley, Schweizer, &
23 Bertrams 2015). Furley et al. (2015) suggest that dual-process theories provide a sound
24 theoretical basis for sport psychology research. However, dual processes may be limited in
25 application. For example, the theory is restricted to a dichotomy in thinking systems which

1 assumes consistency regarding automatic and controlled thinking whilst largely neglecting
2 individual differences (e.g., motivation, cognitive ability, or experience; Evans & Stanovich,
3 2013). Moreover, much of this work fails to account for a basic objective measure of
4 attention – which is addressed in the current study.

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

21 **Athletic Expertise and Performance on Attention and Working-Memory**

22 Research findings regarding the influence of athletic expertise on attention, working-
23 memory-control and working-memory-capacity is equivocal (Furley & Wood, 2016). Whilst
24 some research suggests that experts, at least from sport, do not score significantly higher on
25 measures of working-memory-control and working-memory-capacity (Buszard & Masters,

1 2018; Buszard et al., 2017; Furley & Wood, 2016), other research suggests that working-
2 memory-control differs across athlete expertise (Vestberg et al., 2017). Moreover,
3 experimental work with athletes attests to the importance of working-memory-capacity in
4 tactical decision-making in professional and semi-professional athletes which is reliant on
5 controlled attention (Furley & Memmert, 2012). However, the researchers did not
6 differentiate their findings across expertise, limiting understanding. Additionally, and key to
7 the current study, much research combines working-memory-control and working-memory-
8 capacity together, possibly masking effects associated with these unique processes.
9 Inconsistencies in the literature may be due to methodological differences, such as, no
10 consistent framework of athlete expertise (Swann et al., 2015), or a failure to objectively
11 measure attention (e.g., Laurin & Finez, 2019).

12 To our knowledge, no study has directly tested attention, working-memory-control,
13 and working-memory-capacity using neurocognitive measures, thus limiting understanding of
14 the interplay between these complex cognitive processes. Considering prior work and theory
15 (e.g., building-block-hypothesis; Hambrick, Macnamara, Campitelli, Ullénjj, & Mosingjj,
16 2016) suggesting that expertise is comprised of domain-general and domain-specific factors,
17 it is likely that those with more expertise, who score higher on attention, working-memory-
18 control and working-memory-capacity, may also perform better in sport tasks.

19 **The Current Study**

20 In sum research reports mixed conclusions regarding the interplay between attention,
21 working-memory-control, working-memory-capacity and sport performance across athletic
22 expertise. However, reconciliation of findings is difficult due to inconsistencies and
23 limitation in methodologies, and underpowered analyses trivialising effects. Previous work is
24 yet to provide a cognitive measure of attention using multiple measures to capture the
25 complexity of this process (i.e., adapting attentional resources via greater visual search

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

7 **Materials**

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

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

23 Visual search with a speed/accuracy trade-off was assessed with the MTS, a measure
24 which assesses the participant's ability to match visual samples. The participant is shown a
25 complex visual pattern in the middle of the screen. After a short delay, a varying number of

1 similar patterns are shown around the edge of the screen increasing along trails. Only one of
2 these patterns matches the previously displayed one. Efficient performance requires the
3 ability to ignore the distractor patterns and to indicate the correct one. The outcome measure
4 is percent correct across all trials. Higher scores indicate better performance.

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

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

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

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

7 **Procedure**

8 Participants were recruited via sports coaches as gatekeepers. The study was approved
9 by the university ethics committee in the United Kingdom. Before participants began, they
10 read information sheets and provided informed consent. Participants completed the cognitive
11 tests first in a counterbalanced order. Testing was completed on a GIGABYTE 7260HMW
12 BN touchscreen computer running a Pro Windows 8 operating system with a high resolution
13 13-inch display. Participants then completed the basketball task. Testing lasted approximately
14 40 minutes. Following testing, participants were debriefed and thanked. Data was collated
15 and retrieved from CANTAB and entered onto the SPSSv24 for preliminary analysis.

16 **Design and Analysis**

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

24 Descriptive statistics, ANOVA's testing differences across groups, and zero-order
25 correlations exploring relationships were requested. Regression modelling was used to

1 determine a relationship between the predictors (i.e., RVP & MTS) and outcome variable
2 (i.e., basketball free-throw task).

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

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

1 Comparative Fit Index (CFI) and Tucker Lewis Index (TLI) are .90 or greater (Hu & Bentler,
2 1999). In order to select the most parsimonious model from the tests of invariance, the Bayes
3 information criterion (BIC) and Akaike's information criterion (AIC) were used. The AIC
4 and BIC assign a greater penalty to model complexity and therefore select more efficient
5 models (Byrne, 2012). Chen (2007) suggests that changes below .01 and .015 in the CFI and
6 RMSEA, respectively, would be supportive of an invariant model in relation to the previous
7 model.

8 **Results**

9 **Preliminary Analyses**

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

20 **Structural Equation Modelling**

21 A measurement model consisting of the four cognitive measures and performance
22 measure was created (i.e., RVP, MTS, SSP, SWM & Performance; see Figure 1). The results
23 indicated acceptable fit to the data $\chi^2(7) = 21.33, p < .01$, RMSEA = .056 95% (CI = .052–
24 .059), SRMR = .055, TLI = .932, CFI = .921, AIC = 4356.212, BIC = 4471.652. Parameter
25 estimates indicated all direct paths were significant, suggesting that working-memory-control

1 and working-memory-capacity may fully mediate the attention-performance relationship.
2 Specifically, RVP ($\beta = -.12$, $SE = .08$, $p < .01$) and MTS ($\beta = -.09$, $SE = .04$, $p < .01$) was
3 negatively related to SWM, whereas RVP ($\beta = .13$, $SE = .02$, $p < .01$) and MTS ($\beta = .10$, SE
4 $= .05$, $p < .01$) was positively related SSP. The performance link was negative with SWM (β
5 $= -.10$, $SE = .06$, $p < .01$), whereas SSP ($\beta = .15$, $SE = .04$, $p < .01$) was positive.

6 To test mediation, the partial mediation model with the direct paths not constrained
7 against the full mediation model with direct paths constrained to zero were compared. Results
8 indicated the full mediation model was a good fit $\chi^2(8) = 24.45$, $p < .01$, $RMSEA = .056$ with
9 95% CI (.051–.063), $SRMR = .052$, $TLI = .941$, $CFI = .939$, $AIC = 4137.667$, $BIC =$
10 4289.347 . The partial mediation model was not a significantly better fit to the data $\Delta\chi^2(2) =$
11 1.25 , $p < .01$ implying full mediation. The significant mediating effect of working-memory-
12 control and working-memory-capacity indicated that the RVP and MTS exerted indirect
13 effects on performance through the simple mediating effect of SWM and SSP (see Table 2).

14 Multigroup analyses examined whether the mediation model differed across athlete
15 expertise (i.e., moderation). Comparison of the configural model (e.g., all parameters allowed
16 to be unequal across groups) against the metric model (e.g., holding loadings equal across
17 groups) indicated significantly poorer fit $\chi^2(12) = 9.52$, $p < .01$ with changes in both
18 $\Delta RMSEA = .014$ and $\Delta CFI = .019$. Comparisons against the scalar model (e.g., constraining
19 factor loadings and intercepts across groups) also produced poorer fit $\chi^2(16) = 10.24$, $p < .01$
20 with further changes in both $\Delta RMSEA = .021$ and $\Delta CFI = .014$, thus providing evidence of
21 non-invariance. The configural ($AIC = 4227.658$ & $BIC = 4364.517$) model also indicated
22 lower AIC and BIC values in comparison to the metric ($AIC = 4375.697$ & $BIC = 4488.364$)
23 and scalar ($AIC = 4482.876$ & $BIC = 4593.931$) models. Path coefficients of separate
24 multigroup models highlighted differences in estimates across athlete expertise groups. For
25 example, estimates were in general stronger for the super-elite groups (see Table 3).

1 2017; Buszard & Masters, 2018). Moreover, there may be a reciprocal relationship between
2 working-memory-capacity and expertise which results in improved performance (Buszard et
3 al., 2017).

4 Findings related to the second aim confirm our hypothesis, of working-memory
5 mediating the relationship between attention and performance support predictions. Findings
6 from the mediation model suggest that the influence of attention (i.e., visual search sensitivity
7 and the ability to ignore distractor patterns) on motor performance is determined by working-
8 memory-capacity (i.e., memory span length) and working-memory-control (i.e., ability to
9 manipulate information). This finding supports previous work outside of sport (Ku, 2018;
10 Yogev-Seligmann et al., 2008), but disagrees with previous work in sport regarding the
11 moderating effect of athletic expertise (e.g., no difference across expertise; Furley & Wood,
12 2016).

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

1 development and performance (Awh et al., 2006). The current research provides a foundation
2 for future work to further investigate this interaction.

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

17 **Limitations and Future Directions**

18 The present study has several strengths, such as use of SEM with a large sample, and
19 standardised framework of expertise. There are however some limitations which should be
20 addressed in future work. For example, the cross-sectional design limits causality and
21 direction, and using single measures provides only a snapshot of ability. Moreover, designs
22 that determine causality and direction should be adopted (e.g., longitudinal). Future work
23 should endeavour to include multiple measures of working-memory-control and working-
24 memory-capacity to examine consistency across tasks. Likewise, although attempts were
25 made to increase the ecological application of the model, the methodology was heavily

1 focused upon visual processes and auditory/phonological processes may also play an
2 important role (Baddeley, 2003). Further, other variables may explain the effects reported.
3 For example, the transference of cognitive skills may not be due to sport participation but
4 other cognitively engaging activities such as playing video games. One important
5 confounding variable in the area of cognitive sport psychology is physical activity/fitness
6 (Hertzog, Kramer, Wilson, & Lindenberger, 2008; Hillman, Khan, & Kao, 2015). For
7 example, enhanced cognitive function may be a result of increased physical fitness.
8 Specifically, aerobic exercise has been shown to affect cognitive functioning in the prefrontal
9 cortex which is closely related to WM and executive functioning (Hillman, Erickson, &
10 Kramer, 2008). Whilst increases in athletic expertise should coincide with increases in
11 physical fitness (e.g., professionalism towards sport, Swann et al., 2015), we did not control
12 for this important factor. Future research should control for physical fitness/activity or
13 include high-fit age-matched groups for comparison (Hertzog et al., 2008; Hillman et al.,
14 2008; 2015).

15 Although the current work used a cognitively engaging measure of motor
16 performance, future work could extend these findings by providing a test of different
17 cognitive load levels, similar to previous research (e.g., Laurin & Finez, 2019), and a direct
18 test of attentional-control-theory (Eysenck et al., 2007) by manipulating pressure scenarios to
19 examine the model's efficacy with regards to choking (Hill, Hanton, Matthews & Fleming,
20 2010) building on the work of Wood and colleagues (2016). We also recommend examining
21 whether training both attention and working-memory helps to cope with the negative effects
22 of pressure (Ducrocq, Wilson, Smith, & Derakshan, 2017). Also, inclusion of the athletic
23 expertise framework utilised may reveal important individual differences in how athletes
24 process anxiety in relation to their cognitive processes. Finally, whilst the basketball free
25 throw task taps attention and working-memory concurrently, it may not place sufficient

1 demands on working-memory-control or working-memory-capacity and a more complex task
2 involving elements of in-situ decision-making or performing under pressure would provide
3 greater insight into these processes. Testing the model in this respect in future work would
4 increase its application for researchers and practitioners.

5 **Conclusion**

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

19

20

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5 and attention in gait. *Movement Disorders*, 23(3), 329-342.
- 6
- 7 **Disclosure statement**
- 8 No potential conflict of interest was reported by the authors.

1 **Table 1**

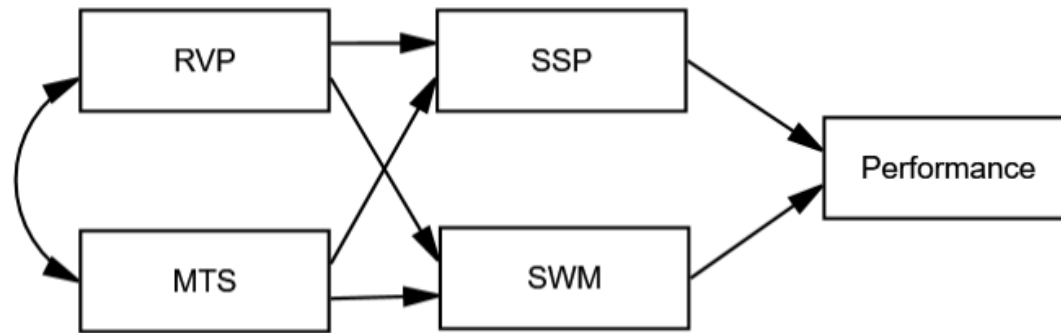
2 Descriptive statistics & zero-order correlations

Measure	M (SD)					η^2	Zero-order Correlations			
	Total	Super-elite	Elite	Amateur	Novice		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**

3 Note. N = 359. RVP = Rapid Visual Information, MTS = Match to Sample Visual Search, SSP = Spatial Span Task & SWM = Spatial Working-

4 Memory, Performance = Basketball Free-Throws.

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



1

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

3 relationship.

1 **Table 2**

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

3 Note. RVP = Rapid Visual Information, MTS = Match to Sample Visual Search, SSP =

4 Spatial Span Task & SWM = Spatial Working-Memory, Performance = Basketball Free-

5 Throws. Pathway significant if confidence interval does not cross zero.

6

7 **Table 3**

8 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

9 Note. RVP = Rapid Visual Information, MTS = Match to Sample Visual Search, SSP =

10 Spatial Span Task & SWM = Spatial Working-Memory, Performance = Basketball Free-

11 Throws. * $p < .05$ ** $p < .01$