

Are Expert Athletes ‘Expert’ in the Cognitive Laboratory? A Meta-Analytic Review of Cognition and Sport Expertise

MICHELLE W. VOSS^{1*}, ARTHUR F. KRAMER¹,
CHANDRAMALLIKA BASAK¹,
RUCHIKA SHAURYA PRAKASH¹ and BRENT ROBERTS²

¹*Beckman Institute for Advanced Science and Technology, University of Illinois at Urbana-Champaign, 405 N. Mathews Ave., Urbana, IL 61801, USA*

²*Department of Psychology, University of Illinois at Urbana-Champaign, 603 East Daniel Street, Champaign, IL 61820, USA*

SUMMARY

Recent literature has demonstrated the usefulness of fitness and computer-based cognitive training as a means to enhance cognition and brain function. However, it is unclear whether the combination of fitness and cognitive training that results from years of extensive sport training also results in superior performance on tests of cognitive processes. In this study we examine, in a quantitative meta-analysis ($k = 20$), the relationship between expertise in sports and laboratory-based measures of cognition. We found that athletes performed better on measures of processing speed and a category of varied attentional paradigms, and athletes from interceptive sport types and males showed the largest effects. Based on our results, more research should be done with higher-level cognitive tasks, such as tasks of executive function and more varied sub-domains of visual attention. Furthermore, future studies should incorporate more female athletes and use a diverse range of sport types and levels of expertise. Copyright © 2009 John Wiley & Sons, Ltd.

Recent research has demonstrated the utility of fitness training on improving cognitive functioning and changing structural and functional aspects of the human brain (Colcombe & Kramer, 2003; Kramer & Erickson, 2007). Cognitive abilities can also be improved with individualized adaptive training and these improvements are reflected in more efficient neural networks (Bherer, Kramer, Peterson, Colcombe, Erickson, & Bécic, 2005; Erickson et al., 2005, 2007). An extension of these two lines of research is the combination of fitness and cognitive skill training. A real-world environment where such combined fitness and cognitive skill training is realized is competitive sports training. Even though plays or techniques are often mastered by competition time, athletes continuously train to improve their mental focus amid distraction (e.g. ‘mental toughness’), or they may study opponents’ strategies and try to integrate these memories as cues for responding correctly during competition. Yet, previous research on the relationship between sport expertise and laboratory-based measures of attention and cognition has shown contradictory findings,

*Correspondence to: Michelle W. Voss, Beckman Institute for Advanced Science and Technology, University of Illinois at Urbana-Champaign, 405 N. Mathews Ave., Urbana, IL 61801, USA. E-mail: mvoss@uiuc.edu

due in part to small sample sizes and methodological heterogeneity. Small sample sizes often result in apparently contradictory results not because of a lack of effect, but because of low power to detect effects even if they truly exist (Schmidt, 1992). A robust solution to the deceptive variability of research findings based largely on a series of underpowered studies is to perform a quantitative meta-analysis (Lipsey & Wilson, 2001). By leveraging the combined power across studies, meta-analyses can often reveal stable patterns that are essentially hidden by typical approaches to statistical evaluation.

Generally two broad approaches pervade the sport-cognition literature. The *expert performance approach* studies the athlete under a sport-specific, or an ecologically valid, context (Ericsson, 2003; Singer, 2000). Tasks utilized under this approach present sport-specific displays and are designed to simulate the sport context; eye-movement recording is often employed to measure expert-novice differences in visual behaviour during the task. Therefore, this perspective on studying sport expertise focuses on variables representative of the direct interaction between the athlete and their environment of expertise (Singer, 2000). Overall, the expert performance approach has found that experts perform better than non-experts on sport-specific tests of declarative memory, attention and attentional allocation, perception or information pick-up, anticipation and decision-making skills and memory for sport-specific environmental information (for reviews see Mann, Williams, Ward, & Janelle, 2007; Starkes & Ericsson, 2003; Williams, Davids, & Williams, 1999). A recent meta-analytic review (Mann et al., 2007) of paradigms using this approach revealed that athletes consistently performed faster and more accurately on tasks of sport-specific decision-making, anticipation, spatial memory and visual search. Interestingly, athletes in interceptive-dominant sports, which require coordination between a participant's body, parts of the body or a held implement and an object in the environment (Davids, Savelsbergh, Bennet, & Van der Kamp, 2002) (e.g. squash, tennis), had faster response times than athletes in an 'other' category which included closed, self-paced sports such as golf and swimming. In addition, results of eye-tracking measures demonstrated that experts made fewer fixations and had longer fixation durations than non-experts during sport-specific tasks.

While the expert performance approach allows experts to closely transfer skills from the field to the laboratory, one could argue that measures of fundamental cognitive abilities in simulated sport environments are confounded by the athletes' superior declarative and procedural knowledge. Some examples might include task maintenance, situational probabilities and distracter and target salience. Certainly the expert performance approach is invaluable when the goal is to examine expertise differences in sport-specific cognition. However, this approach may be less appropriate for determining whether expertise in sport is related to superior performance on fundamental cognitive measures outside of the sport context.

Thus, the *cognitive component skills* approach, of primary interest in this meta-analysis, examines the relationship between sport expertise and performance on measures of cognition that presumably tap into some of the fundamental cognitive demands of competitive sport training (Nougier, Stein, & Bonnel, 1991). Studies of this kind strip the testing environment of the sport context. The cognitive component skills approach has been criticized for not capturing the complexities of the environment that generates superior expert performance (Ericsson, 2003). However, we believe the approach has important implications for capturing and characterizing the fundamental cognitive skills associated with competitive sport training. Thus, we believe there may be both sport-specific and sport-general cognitive enhancements from competitive sport training. Yet, research based on the cognitive component skills approach has yielded mixed results. While some studies have found evidence for better performance of athletes on basic tests of cognition

(Anzeneder & Bosel, 1998; Castiello & Umilta, 1992; Nougier, Ripoll, & Stein, 1989; Nougier, Rossi, Alain, & Taddei, 1996), other studies have found no performance benefits on cognitive measures in favour of athletes (Helson & Starkes, 1999; Lum, Enns, & Pratt, 2002; McAuliffe, 2004; Starkes, 1987). As noted above, a meta-analytic approach may provide some clarity on this contradictory pattern of results.

A meta-analytic approach also affords the opportunity to examine the effect of potential moderators of cognitive component skills studies, as some of the heterogeneity in findings may result from variables that are either not controlled for in specific studies or lack a substantial sample size within-study to see statistically significant effects. Mixed findings could arise due to variation in methodological factors such as the laboratory tasks used to measure aspects of cognition, participants' sport, level of expertise, or gender (Lum et al., 2002; Nougier et al., 1989). In the present study, we attempt to summarize results across the various cognitive paradigms that have been used with this approach. Thus, categories of cognitive measures were determined based on the tasks used in the existing literature, and with respect to paradigms that could be grouped such that the validity of aggregating their measures would be preserved. Initial task categorizations were based on description of neuropsychological tests in Lezak, Howieson, and Loring (2004) and knowledge of previous literature on cognition and perception. Given sufficient reporting of the results, tasks were also broken down into sub-components in cases in which enough studies could be collapsed across condition to examine a sub-component measure. This process resulted in three categories of dependent variables, including measures of attentional cuing (and sub-components of endogenous and exogenous cuing conditions), processing speed and a category of varied attention tasks.

Attentional cuing paradigms measure one's ability to utilize relevant visual cues in the environment, and to quickly disengage from irrelevant cues (Posner & Fan, 2008). Relatively simple paradigms are often used in which subjects are cued to orient attention to one of multiple locations and a target either appears in the cued location or an uncued location (Pashler, 1999). Reaction time measures are used to index the mental chronometry of shifts of attention among the available display locations. It is thought that cued visual attention, or flexibility of attention, enables an expert athlete to minimize the effects of unexpected events by being able to efficiently disengage attention from uninformative cues such as feints. *Endogenous cuing* refers to when the cue, usually symbolic such as an arrow, provides information about where the target is likely to appear; the informative cue prompts the participant to voluntarily shift attention to the likely target location. In contrast, *exogenous cuing* refers to when the cue provides no information about where the target will appear, and so it is in the best interest of the participant to ignore the cue; if attention is inadvertently drawn to the uninformative cue, then attention is shifted automatically, or reflexively. These two types of shifts of attention are also called controlled vs. automatic shifts in attention (Pashler, 1999; Posner & Fan, 2008). Traditionally, the dependent measure of interest is the 'attentional cost' of an invalid cue, with greater attentional flexibility characterized by smaller cost. *Processing speed* is measured by response efficiency in information processing tasks (e.g. reaction time). Differences in processing speed are believed to be important aspects of both human development and aging (Kail & Ferrer, 2007; Salthouse, 2004). It is thought that processing speed is necessary for quick and accurate reactions in fast-paced sports such as volleyball, hockey, or tennis. A final category was created for effects from higher-level cognitive paradigms, including measures based on models of spatial (Chaddock, 2006; Turatto, Benso, & Umilta, 1999) and divided (Lippold, 1986; Kioumourtzoglou, Kourtessis, Michalopoulou, & Derri, 1998; Starkes, Allard, Lindley, & O'Reilly, 1994) attention. Thus,

we call this category *varied attention paradigms*, since each study has in common the demand of focusing attention on task-relevant stimuli (whether that be one or multiple) while inhibiting allocation of attention to task-irrelevant distractions.

Studies were also coded to evaluate the roles of moderator variables such as level of expertise, sex and sport type, in the sport-cognition relationship. Level of expertise was examined by comparing professional athletes to college varsity athletes. We also considered gender as a potential moderator variable. Lastly, we examined sport type. Sports were defined as *static* if they generally involved highly consistent, self-paced situations (e.g. long distance running, swimming); *interceptive* sports were defined as any sport that dominantly requires coordination between a participant's body, parts of the body or a held implement and an object in the environment (Davids et al., 2002) (e.g. tennis, fencing, boxing); *strategic* sports were defined as sports that involved simultaneously processing a substantial amount of information regarding teammates, opponents, field position and ball, and often involve highly varied situations (e.g. volleyball, basketball, soccer, hockey, field-hockey, water-polo) (Singer, 2000). Different sport types impose characteristically different sets of mental demands upon the athlete; if experience is the driving force behind mechanisms of brain plasticity, then sport type is also a potential moderator of the sport-cognition relationship.

METHOD

Literature search

The literature search focused on the online databases PsychInfo, MedLine, Current Contents, Education Research in Completion (ERIC), Sport Discus and Dissertation Abstracts Online. Combinations of the following keywords were used: *Sport, cognition, cognitive, memory, spatial memory, expertise, attention, visual attention, pattern memory, spatial attention, perception, visual search, processing speed, information processing, athlete, student-athlete, review* and *meta-analysis*. Periodic searches of these databases were conducted until the end of December 2007. In addition, articles were identified from reference lists of obtained articles, dissertations and book chapters. Finally, to find unpublished data and conference proceedings personal communication was employed via a sport psychology listserv (APA Div 47 listserv) and email inquiry to experts in the area of sport and cognition and perception; we also included one unpublished neuropsychological test data set from our own laboratory (Voss, Neider, Carbonari, & Kramer, 2007) that we do not plan to submit for publication due to non-significant statistical results.

Eligible studies must have been available in English translation and involve a controlled laboratory examination of cognitive skills, and a comparison of expert athletes and a matched control group of non-expert athletes. Control groups of non-experts had to be comprised of comparable age and sex groups to the expert athlete group and have no history of self-reported experience at the expert level in the sport of the expert athlete group. Sport was defined as consisting of physical activity, competition and a scoring system. Exceptions are target games such as golf and archery, due to their relative lack of physical fitness demands. Given previous research that has shown the cognitive benefits of increased aerobic fitness (Hillman, Erickson, & Kramer, 2008; Kramer & Erickson, 2007), we believe that excluding sports with no requirement of running or jumping would minimize the potential confound of individual differences in participants that are not due to

the cognitive demands of sport training. An expert athlete was defined as being part of a competitive team or level of competition such as top-level amateur leagues and professionals (where players are paid for their skills) or high school and college varsity athletics. While indeed there is a subset of the best collegiate competitors that participate at the international level as well, college athletics specifies that one cannot participate on a collegiate team *and* get paid for their sport for profit. Therefore, while a small subset of collegiate athletes could participate in international competitions such as the Olympics, they are still considered an amateur athlete unless they are able to play sport as a paid profession. While there may be some overlap with a small subset of athletes that could be in both categories, we do not believe there would be enough overlap to warrant the categorization invalid. Therefore, papers that reported participants were college athletes were coded as collegiate level and participants that were reported as part of a national team or as professional athletes were coded as professional.

In the current study, we focused on aggregating sport-cognition research in the domain of the cognitive component skills approach. Our criteria for considering a study eligible in this regard was that the study must have conducted a laboratory test of cognitive abilities, without the use of sport displays or stimuli. Therefore, studies that utilized sport-specific two-dimensional displays (computer display, video, or slides) were deemed *ineligible* for this meta-analysis. This excluded a number of studies using the probe technique, temporal occlusion, eye movement dependent variables, or coincident timing, since these techniques are primarily used with sport-specific displays. Overall 128 sources were collected with relevant abstracts, however, the final body of literature consisted of 20 studies (see Figure 1). Reasons for ineligibility included lack of non-expert control group, inadequate statistics reported, use of sport-specific displays, or inclusion of athletes who were selected on basis of activity rather than superior performance. One study was excluded because the athletes were outliers in age (Rotella & Bunker, 1978); participants in this study were over

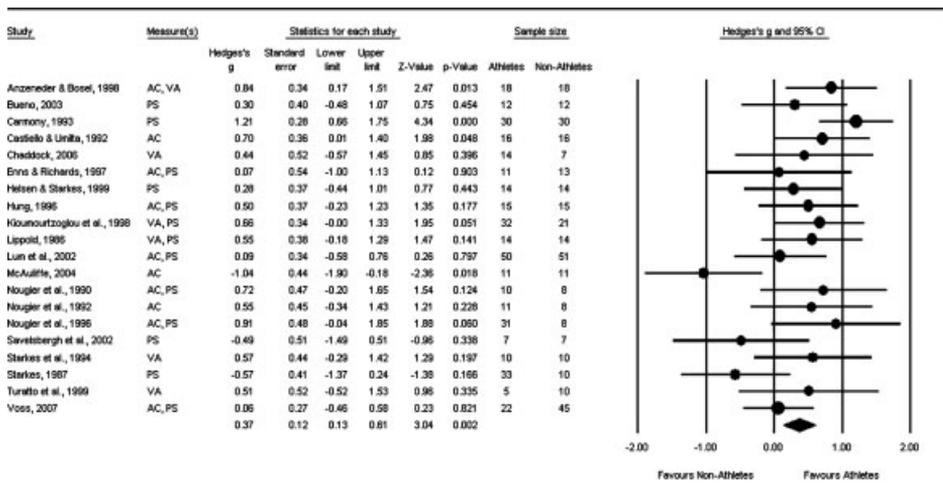


Figure 1. Summary of overall athlete effect (study-level effect size). Note: AC, attentional cuing; PS, processing speed; VA, varied attention paradigms: marker and line width proportional to study's weight in analysis

65 years of age, while the mean age for other studies was below 25 years. From the 20 studies, 198 effect sizes were derived including overall effects and effects based on various aggregations of moderator variables across and within cognitive measures.

Coding of outcomes

Each task was categorized as one of the cognitive measures delineated above (attentional cuing, processing speed, or varied attention paradigms). Attentional cuing paradigms with results for multiple stimulus onset asynchronies (SOAs) (e.g. Enns & Richards, 1997; Lum et al., 2002) were coded such that cuing effects of facilitatory SOA conditions (all SOAs for endogenous cuing; SOAs < 300 ms for exogenous cuing) were positive when athletes showed less cost of invalid cuing conditions (Pashler, 1999; Posner & Fan, 2008). Only two studies (Enns & Richards, 1997; Lum et al., 2002) included conditions with SOAs in the exogenous cuing condition long enough (>300 ms) to elicit an inhibitory effect (inhibition of return, IOR). These effects were coded such that shorter IOR in favour of athletes was a positive effect. The overall cuing effect is thus an aggregate of endogenous and exogenous facilitatory orienting of attention, and suppression effects of IOR; this represents an overall ability to flexibly engage and disengage allocation of attention to locations in space (Pashler, 1999; Posner & Fan, 2008). Condition-specific effects were also coded to compare facilitatory endogenous and exogenous conditions, and IOR conditions, separately. Finally, methodological, sport and participant characteristics were coded to determine their importance in the sport-cognition relationship. Two researchers did coding independently, with expertise in the fields of attention, cognition and perception. Inter-rater reliability was computed using dummy coding for effect sizes where coding differed by rater. Cohen's κ was computed as a measure of inter-rater reliability, $\kappa = .65$, indicating good agreement. When a discrepancy in coding was encountered, the raters discussed and agreed on the best coding procedure for that effect size.

Effect size calculation and analysis

Effect sizes were calculated using Comprehensive Meta-Analysis software package, Version 2 (BioStat, Englewood, New Jersey). Hedges's (1982) formula was used to calculate effect sizes for each study: $g = (M_{\text{athlete}} - M_{\text{control}}) / SD_P$, where M_{athlete} is the athlete group mean, M_{control} is the control group mean and SD_P is the pooled standard deviation. All effect sizes were weighted by Hedges's sample-size correction: c^*g , where $c = 1 - [3/(4m-9)]$, and $m = 2N - 2$. Effect sizes were coded so that positive numbers reflected better athlete performance.

Once effect sizes were generated, a random-effects model was fit to the data to determine the effect of sport expertise on cognition. For this analysis, effect sizes for multiple dependent variables within studies (e.g. cognitive measures) were averaged to generate a mean effect size estimate per study. A Q -test was used to assess heterogeneity of effect sizes (Rosenthal, 1995). To test the effects of moderator variables (regardless of cognitive measure) we used a random-effects model with moderators, or a mixed-effects model (Overton, 1998; Raudenbush, 1994; Viechtbauer, 2006). A random-effects model assumes that the effect sizes differ randomly in the population, with no systematic variation (e.g. moderators), whereas a mixed-effects model assumes some systematic variation in the effect sizes (moderators) and also some random population variance. Therefore, a mixed-effects model provides a conservative method of estimating moderator effects.

Moderators were assessed individually by partitioning the effect sizes into groups based on the moderator variable of interest. While it would have been optimal to do a multiple regression test of moderators, there was not enough data to subdivide effect sizes into uniquely representative sub-groups of multiple moderator variables. As a result, the mixed-effect model is analogous to mixed-effects ANOVA. The Q_{ME} statistic indicated whether there was significant between-groups variance between the two groups of effect sizes, and a significant Q_{ME} signified that the moderator variable had significant influence on the effect sizes. Mixed-effect models provide a more stringent test of moderators and help to diminish the possibility of Type I errors, which can become severely inflated in the typical fixed-effects with moderators approach to meta-analysis (Viechtbauer, 2007). The amount of heterogeneity was estimated with a restricted maximum-likelihood estimation (REML) (Raudenbush & Bryk, 2002). REML estimates are approximately unbiased, as opposed to regular maximum-likelihood estimates, which tend to be small on average. Meta-analytic models were fit using a custom S-plus function by Wolfgang Viechtbauer (Viechtbauer, 2006, www.wvbauer.com/).

To determine the effect associated with different cognitive measures, effects from each category of cognitive measures were aggregated separately. Like above, analyses were done with the most conservative random-effects model with the assumption that hypothesized moderators would contribute, in addition to random variance, to mean effect sizes. To test the effects of moderator variables for a category of cognitive measures we again used a mixed-effects model (Overton, 1998; Raudenbush, 1994; Viechtbauer, 2006). The same procedure as described above was used for fitting mixed-effects models for moderators within separate cognitive abilities.

Finally, we tested the likelihood of publication bias by using a trim and fill procedure (Duval & Tweedie, 2000). Publication bias reflects the possibility that the studies retrieved for the meta-analysis may not include all studies actually conducted, with the most likely omissions being studies that failed to find statistically significant results. Therefore, effects may be sensitive to publication bias, and should be adjusted, if they are comprised of a skewed distribution of studies; typically, published studies with higher standard error show effects larger than the 'true' theoretical population effect while studies with the lowest standard error tend to show effects closest to the population effect, potentially creating a gap of missing studies with high standard error and effect size estimates that tend to be lower than the population effect- resulting in a biased overestimate of the population effect. Therefore, the trim and fill procedure (Duval & Tweedie, 2000) is a nonparametric statistical technique that examines the symmetry and distribution of effect sizes plotted against the inverse of the variance or standard error. This technique first estimates the number of studies that may be missing as a result of publication bias, then the trim and fill procedure calculates hypothetical effects for potentially omitted studies and then re-estimates the average effect size and confidence intervals on the basis of the influence of studies that would have been included in the analysis if they had been published.

RESULTS

Descriptive statistics of sampled studies

The 20 sampled studies included 694 participants. Groups were well balanced with approximately 53% (366) of all participants being athletes. The average age of the sample

was 21.4 years (based on a subset of articles that reported descriptive statistics for age); the average age for athletes and non-athletes was not statistically different ($p > .05$). Of the studies that reported gender the athlete group included of 63.7% males; 25.4% of studies did not report gender. Regarding expertise, an overwhelming majority of the sample was composed of professional (48.4%) or college varsity athletes (40.1%). The majority of studies were described in peer-reviewed journal articles (75%) and the remaining sources were doctoral dissertations or unpublished data (Chaddock, unpublished manuscript; Voss et al., unpublished data). Of the 20 papers sampled, 11 were from Kinesiology or Human Movement laboratories; the others were from Psychology laboratories. Since research quality was deemed comparable across included studies, this was not examined as a potential moderator. Effect sizes are interpreted using Cohen's (1992) guidelines. Small effects are in the .1–.3 range, medium .4–.6 and large in the range $> .70$.

Overall effects of athlete, expertise level, sex and sport type

The overall effect of athlete was computed by averaging effect sizes for multiple dependent variables within studies (e.g. cognitive measures) to generate a mean effect size estimate per study. This resulted in a small-to-medium-sized effect of athlete for the sampled studies ($g = .37$; $p < .05$) that was statistically heterogeneous ($Q = 35.89$; $p < .05$). Figure 1 lists the studies, sample sizes and illustrates effect sizes and 95% confidence intervals for individual studies. Trim-and-fill analyses did not indicate publication bias.

Next, we determined whether there were overall moderator effects for sport type, expertise, or sex (see Figure 2). Only gender significantly accounted for heterogeneity in study-level effect sizes ($Q_{ME(1)} = 9.61$, $p < .05$). Overall, males had a greater effect size ($g = .49$; $p < .05$) than females ($g = -.18$; $p > .05$). Effects varying by expertise did not account for a significant amount of variance in effect heterogeneity ($p > .05$). Sport type (static, interceptive, strategic) accounted for variance in effects with marginal statistical significance ($p = .11$), however, it is interesting to note that only the aggregate effect size for interceptive sports was statistically significant ($g = .71$; $p < .001$), followed by strategic sports ($g = .27$; $p > .05$) and static sports ($g = .10$; $p > .05$).

Athlete vs. non-athlete effects on specific cognitive measures

Next, the effects within each cognitive domain were examined. Here, we tested not only for heterogeneity of effects within each cognitive measure but also for exploratory purposes, we tested moderator variables when there were at least two studies that could be grouped for at least two levels of the moderator variable (sport type, sex and expertise).

Attentional cuing

Recall that cued visual attention reflects one's ability to utilize environmental cues and recover from unexpected events in the environment. Effects were small, and not statistically significant, for measures of attentional flexibility in attentional cuing paradigms ($g = .17$; $p > .05$), see Figure 2. The Q -test for heterogeneity was statistically significant ($Q = 30$, $p < .05$). None of the moderator variables (sex, expertise and sport type) accounted for the variance in effect sizes of attentional cuing paradigms (all $Q_{ME} p > .05$). Next, effect sizes were sorted based on whether the cuing condition was endogenous or exogenous in nature. While endogenous cuing conditions ($g = .20$; $k = 9$; $N = 371$) showed

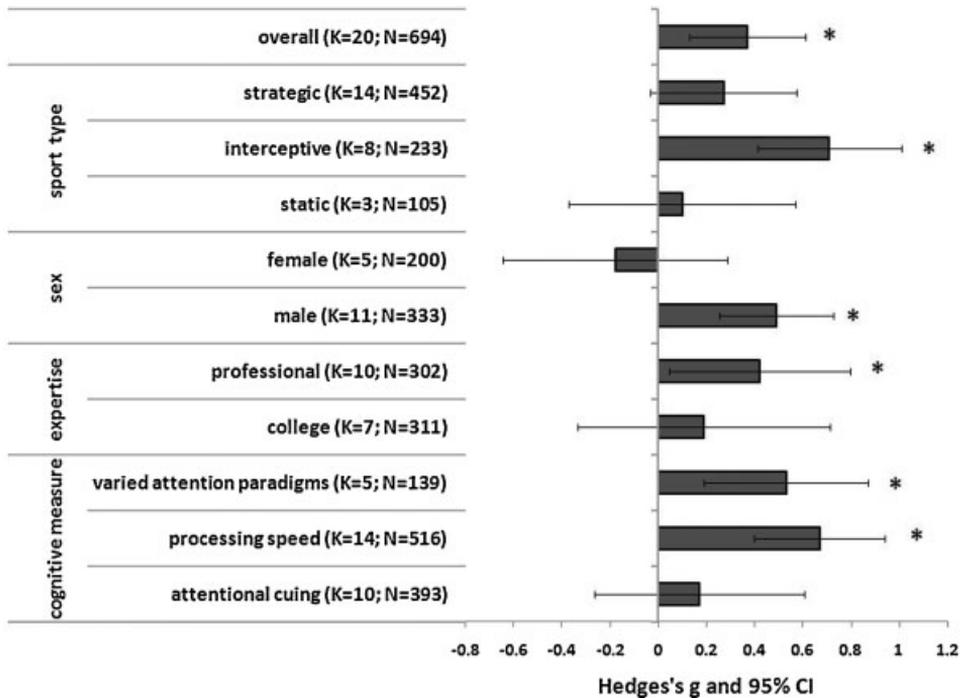


Figure 2. Effects broken down by sport type, sex, expertise and cognitive measure

a greater effect size in favour of athletes than exogenous cuing ($g = .05$; $k = 4$; $N = 191$), their difference was not statistically significant ($p > .05$).

Processing speed

Paradigms that examine processing speed measure one's ability to quickly and accurately perceive and respond to environmental stimuli. The effect size for processing speed was medium ($g = .67$; $p < .05$). No publication bias was detected from a trim-and-fill analysis. The Q -test for heterogeneity was statistically significant ($Q = 40.58$, $p < .05$). However, when effect sizes were aggregated by moderator variables of sex, expertise and sport type, none of the moderator variables accounted for the variability in effect sizes (all Q_{ME} $p > .05$). Despite this, similar to the overall moderator analysis, of the different sport types, interceptive sports showed the largest statistically significant effect ($g = .96$; $p < .05$), followed by strategic sports ($g = .45$; $p < .05$), while there was only one static sport sample for processing speed.

Varied attention paradigms

The aggregate effect size for this group of studies was medium ($g = .53$; $p < .05$). No publication bias was detected by the trim-and-fill analysis. Despite the varied paradigms, the Q -test for heterogeneity of effect sizes was not statistically significant ($p > .05$), and all the studies in this category showed positive effects that ranged from .29 to 1.01.

Unfortunately, there was not enough variation in moderator variables to reliably test for moderator effects in this category.

DISCUSSION

The present study investigated the nature and extent of the fundamental sport-cognition relationship. The diverse body of research on sport expertise broadly falls under two perspectives. The expert performance approach studies the athlete under a sport-specific, or an ecologically valid, context (Mann et al., 2007; Starkes & Ericsson, 2003). In contrast, a cognitive component skills approach, studies the relationship between basic measures of cognitive ability and sport expertise (Nougier et al., 1991; Starkes & Ericsson, 2003). The current study quantitatively reviewed the current literature that falls under the umbrella of the cognitive component skills approach. Furthermore, the current study reveals the gaps in the present literature that should be addressed by future empirical research.

We found a small-to-medium sized effect for the overall athlete effect, suggesting that despite the heterogeneity of effects, the average effect remains statistically significant in favour of athletes. Indeed, as Figure 1 illustrates, many of the studies find small, but positive, effects and often they are not statistically significant. However, we were able to aggregate effects across studies, increasing statistical power that was not present in many studies due to small sample sizes of athlete groups or too few athletes in different types of sports within a study. In addition, we found that athletes performed better on measures of processing speed and a category of varied attentional paradigms, and athletes from interceptive sport types and males showed the largest effects on cognitive measures. Finally, we found that similar to the overall moderator analysis of the different sport types, interceptive sports showed the largest statistically significant effect on measures of processing speed, followed by strategic sports, however, there was only one static sport sample for processing speed.

Given the findings of Mann et al., 2007, where static sport athletes showed the smallest effects of response time, we believe with more samples of static sport athletes in basic cognitive paradigms this would have been a more statistically powerful and informative comparison. Nevertheless, it is interesting that we found similar results to Mann et al., 2007, in that athletes of sports with predominantly interceptive actions showed the greatest benefit on measures of processing speed. This is interesting since the Mann et al. study included only sport-specific measures of visual search, anticipation, and decision-making abilities. This suggests that processing speed may be one measure of cognition that transcends sport context. Of course, we cannot rule out from cross-sectional studies, whether athletes are naturally gifted with faster processing speed, and we discuss this as a limitation and direction for future research below. However, this effect is interesting and future studies utilizing the cognitive component skills approach should try to include static sport athletes to serve as a comparison group, in addition to non-athlete controls. Furthermore, given the literature that has shown aerobic exercise enhances cognitive and neural plasticity (Colcombe & Kramer, 2003; Kramer & Erickson, 2007) future studies should also include a group of high-fit age-matched controls. Since the cognitive benefits associated with aerobic exercise have been shown preferentially for higher-level cognition, such as executive function measures, one could predict that aerobically fit individuals with no competitive sport training experience would not show the processing speed benefit compared to interceptive sport athletes.

We also found that gender was an overall moderator, suggesting that males showed more benefit on cognitive measures than female athletes, compared to non-athlete controls. However, there were more studies that used males so future studies should try to recruit both males and females to permit more within-study and across-study comparisons of gender. While we expected that expertise (college vs. professional) would be a significant moderator of cognitive performance, our results did not show this. One explanation may be that very few studies had both college and professional athletes. Thus, a stronger effect may be revealed if more studies were able to compare within-study, the effects of expertise level on cognitive performance. Similar to our discussion of the sport type effects, we cannot rule out the nature vs. nurture problem in comparing levels of expertise without doing longitudinal assessments of cognitive skill and sport expertise.

The category of varied attention paradigms showed a promising positive effect, but their heterogeneity in approaches makes this result something for further examination. Tasks included in the varied attention category included a Paced Auditory Serial Addition Task (PASAT), the Eriksen arrow flankers task (Eriksen, 1995) and tasks of visual short term memory, modulation of spatial attention and a same-difference visual discrimination task. The arrow flanker and modulation of spatial attention (breadth) tasks showed relatively high effects (.47 and 1.01). Interestingly, one interpretation of reduced attentional cuing effects in favour of athletes is that athletes may be more likely to regulate and switch their attention to a more diffuse instead of spatially local attentional mode (Nougier et al., 1989); this is consistent with athletes having a better ability to regulate, or modulate, their mode attentional breadth compared to non-athletes. While we found that cued attention effects were highly variable, effects for endogenous cuing showed more benefit than exogenous cuing (facilitatory or suppressive). This effect was not statistically significant, however, we may speculate this together with positive effects for regulation of attentional focus, suggests sport may involve more top-down regulation of attention than automatic or reflexive orienting of attention. Particularly since a large part of sport deals with regulating where and how attention is allocated- internally vs. externally, and whether external attention is focused diffusely or narrowly. Finally, we found no studies that have examined classic executive function measures such as task-switching, dual task performance, or inhibition. Since many sports depend on fundamental cognitive skills such as these, the latter measures would be interesting for future studies to examine.

Alternatively, some previous literature has described the delineation of cognitive skills that characterize the expert athlete with a 'hardware' vs. 'software' analogy, where hardware represents aspects of the central and peripheral nervous system and software represents a sport-specific skill set that is acquired through sport training (Helson & Starkes, 1999; Starkes, 1987). This research has found that sport expertise effects were largely in the sport-specific tests, or in the software domain compared to the hardware domain. This dichotomy tries to disentangle the nature vs. nurture question. Critically, along this vein, an implication is that hardware is something one is born with and thereafter non-malleable. In contrast, the cognitive component skills approach views sport training as a medium for experience dependent brain plasticity, or cognitive training, that results in more efficient brain networks (both general and sport-specific) resulting in particular cognitive skill profiles. In support of this, we found trends for moderating effects of sport type on cognitive performance. In previous studies, either a narrow range of cognitive domains or low statistical power for sport type comparisons has hindered examinations of sport by cognition interactions (Kioumourtoglou et al., 1998; Lum et al., 2002). Therefore, it will be important for future research to increase statistical power by sampling

larger populations of athletes from a variety of sports and to administer a comprehensive neuropsychological battery that covers a wide range of cognitive abilities.

In general, our results provide a more optimistic view of the ability for basic laboratory tasks to inform the sport-cognition relationship, than has been previously concluded in some previous reviews of the literature (Starkes & Ericsson, 2003; Williams et al., 1999). The current review also differs in that it is a quantitative description of cognitively based studies of sport and cognition. Studies that have approached the problem as 'hardware' vs. 'software' have been based more on measures sensory perception than on theoretically-based cognitive measures such as attentional cuing, information processing speed and selective and divided attention and visual working memory. This stems from the perspective that the central nervous system in sport plays the role of merely a perception-action system. However, the cognitive component skills approach intends to abstract the higher-level cognitive abilities subserved by the central nervous system, that are malleable or plastic in response to experience, and which may play a more general rather than specific role in sport expertise. While each perspective is valuable to form a holistic picture of the sport-cognition relationship, we argue that based on our results, there is a place for the cognitive component skills approach for extending current knowledge about how sport training affects the brain and acquisition of fundamental cognitive abilities.

As mentioned above, an open question is whether athletes that are predisposed to excel at a set of cognitive skills are more likely to then excel at sports that require a matching cognitive skill set to succeed. This is the problem of self-selection: which came first, the potential athlete with a particular profile of cognitive abilities, or the potential athlete that acquires a particular cognitive skill set as a result of experience-dependent learning and brain plasticity? If the latter were true, one should hypothesize that expertise level would moderate the extent that certain cognitive abilities are enhanced in the expert athlete. Indeed, we hypothesized such a relationship would exist; yet while experts had a larger overall effect than college athletes (.42 vs. .19), their difference was not statistically significant. While this question cannot be unequivocally addressed without a longitudinal investigation, we do not believe that the effects in the current study are necessarily due to self-selection. For example, there could be a sport type by expertise level interaction to the extent that professional and collegiate athletes differ-if some sports rely more on physical talent to distinguish professionals and others are based more on cognitive abilities in conjunction with physical talent. In the future, larger cross-sectional studies could examine these questions, but optimally, longitudinal studies should be done that track athletes training at various levels in different sports, to ask how cognitive abilities differ as a function variables of experience (e.g. years of training, type of training, training intensity and duration, etc.). Therefore, a caveat of these results is that sport training is just one of several mechanisms for athletes to show enhanced cognitive skill performance. It is possible (and quite likely) that factors such as genetics or socioeconomic status also play some role in the cognitive performance differences seen here. These questions could not be asked in the present study. However, future studies that elucidate potential changes in the sport-cognition relationship as a function of training and/or age might provide some hints - and perhaps inspiration for longitudinal studies of athletic training.

Finally, it will be important for future research to study whether enhanced cognitive skills as a result of sport transfer to other sports (cognitive cross training) or tasks of every day living such as paying attention throughout a classroom lecture, being productive in a noisy workplace, or driving safely on congested roads and intersections. For example, one applied context of sport expertise research from the cognitive component skills approach is

how sport training affects the student-athlete. Often student-athletes are so busy with their sport and keeping up with classes that there is little room for extracurricular activities or career internships that help other students successfully transition into the workplace after college. Future research should focus on whether cognitive skills associated with extensive sport training transfer to improved performance in specific college academic programs or occupations with comparable task demands. Such a direction for this research has important implications such as improving graduation rates and student-athlete grade point averages, and helping the student-athlete transition from being a college athlete into the career world.

ACKNOWLEDGEMENTS

This research was supported by a grant from the NCAA research committee to the first author.

REFERENCES

*Included in meta-analysis

- *Anzeder, C. P., & Bosel, R. (1998). Modulation of the spatial extent of the attentional focus in high-level volleyball players. *European Journal of Cognitive Psychology, 10*, 247–267.
- Bangert-Drowns, R. L. (1986). Review of developments in meta-analytic method. *Quantitative Methods in Psychology, 99*, 388–399.
- Bherer, L., Kramer, A. F., Peterson, J. S., Colcombe, S., Erickson, K., & Becic, E. (2005). Training effects on dual-task performance: Are there age-related differences in plasticity of attentional control? *Psychology and Aging, 20*, 695–709.
- *Bueno, C. M. A. (2003). The effects of seasonal training on visual reaction time in high school basketball players. *ProQuest Digital Dissertations, AAT 1413296*, Doctoral Dissertation, Southern Connecticut State University, 2003.
- *Carmony, P. (1993). A comparison of choice reaction time in the presence of selected rhythmical auditory stimuli in open and closed skill athletes. *ProQuest Digital Dissertations, AAT 9334241*, Doctoral Dissertation, Florida State University, 1993.
- *Castiello, U., & Umilta, C. (1992). Orienting of attention in volleyball players. *International Journal of Sport Psychology, 23*, 301–310.
- *Chaddock, L. (2006). Sport-specific cardiovascular fitness, cognition, and motor performance: An electrophysiological study of athletes' P300 and LRP brainwave potentials. Unpublished Manuscript.
- Cohen, J. (1992). A power primer. *Psychological Bulletin, 112*, 155–159.
- Colcombe, S., & Kramer, A. F. (2003). Fitness effects on the cognitive function of older adults: A meta-analytic study. *Psychological Science, 14*, 125–130.
- Davids, K., Savelsbergh, G., Bennett, S. J., & Van der Kamp, J. (2002). Interceptive actions in sport: Theoretical perspectives and practical applications. In K. Davids, G. Savelsbergh, S. J. Bennett, & J. Van der Kamp (Eds.), *Interceptive actions in sport: Information and movement*. New York: Routledge.
- Duval, S., & Tweedie, R. (2000). Trim and fill: A simple funnel-plot-based method of testing and adjusting for publication bias in meta-analysis. *Biometrics, 56*, 455–463.
- *Enns, J. T., & Richards, J. C. (1997). Visual attentional orienting in developing hockey players. *Journal of Experimental Child Psychology, 64*, 255–275.
- Eriksen, C. E. (1995). The flankers task and response competition: A useful tool for investigation of a variety of cognitive problems. *Visual Cognition, 2*, 101–118.

- Erickson, K. I., Colcombe, S. J., Wadhwa, R., Bherer, L., Peterson, M. S., Scalf, P. E., et al. (2005). Neural correlates of dual-task performance after minimizing task-preparation. *NeuroImage*, 28, 967–979.
- Erickson, K. I., Colcombe, S. J., Wadhwa, R., Bherer, L., Peterson, M. S., Scalf, P. E., et al. (2007). Training-induced plasticity in older adults: Effects of training on hemispheric asymmetry. *Neurobiology of Aging*, 28, 272–283.
- Ericsson, K. A. (2003). How the expert performance approach differs from traditional approaches to expertise in sport: In search of a shared theoretical framework for studying expert performance. In J. L. Starkes, & K. A. Ericsson (Eds.), *Expert performance in sports: Advances in research on sport expertise* (pp. 371–402). Champaign, IL: Human Kinetics.
- Hedges, L. V. (1982). Estimation of effect size from a series of independent experiments. *Psychological Bulletin*, 92, 490–499.
- *Helson, W. F., & Starkes, J. L. (1999). A multidimensional approach to skilled perception and performance in sport. *Applied Cognitive Psychology*, 13, 1–27.
- 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, 58–65.
- *Hung, T. M. (1996). Are fast-action sport athletes characterized by greater attentional flexibility and motor preparedness? An electrophysiological study of table tennis players. *ProQuest Digital Dissertations*, AAT 9719757, Doctoral Dissertation, University of Maryland, 1996.
- Kail, R., & Ferrer, E. (2007). Processing speed in childhood and adolescence: Longitudinal models for examining developmental change. *Child Development*, 78, 760–770.
- *Kioumourtoglou, E., Kourtessis, T., Michalopoulou, M., & Derri, V. (1998). Differences in several perceptual abilities between experts and novices in basketball, volleyball, and water-polo. *Perceptual and Motor Skills*, 86, 899–912.
- Kramer, A. F., & Erickson, K. I. (2007). Capitalizing on cortical plasticity: Influence of physical activity on cognition and brain function. *Trends in Cognitive Neuroscience*, 11, 342–348.
- Lezak, M. D., Howieson, D. B., & Loring, D. W. (2004). *Neuropsychological Assessment* (4th ed.). New York: Oxford University Press.
- *Lippold, S. C. (1986). Attention in professional and amateur boxers. *ProQuest Digital Dissertations* AAT 8616407, Doctoral Dissertation, University of Houston, 1986.
- Lipsey, M. W., & Wilson, D. B. (2001). *Practical meta-analysis* (Vol. 49). Thousand Oaks, CA: California: Sage Publications.
- *Lum, J., Enns, J. T., & Pratt, J. (2002). Visual orienting in college athletes: Explorations of athlete type and gender. *Research Quarterly for Exercise and Sport*, 73, 156–167.
- Mann, D. T. Y., Williams, A. M., Ward, P., & Janelle, C. M. (2007). Perceptual-cognitive expertise in sport: A meta-analysis. *Journal of Sport & Exercise Psychology*, 29, 457–478.
- *McAuliffe, J. (2004). Differences in attentional set between athletes and nonathletes. *The Journal of General Psychology*, 131, 426–437.
- *Nougier, V., Azemar, G., Stein, J.-F., & Ripoll, H. (1992). Covert orienting to central visual cues and sport-practice relations in the development of visual attention. *Journal of Experimental Child Psychology*, 54, 315–333.
- Nougier, V., Ripoll, H., & Stein, J.-F. (1989). Orienting of attention in highly-skilled athletes. *International Journal of Sport Psychology*, 20, 205–223.
- *Nougier, V., Rossi, B., Alain, C., & Taddei, F. (1996). Evidence of strategic effects in the modulation of orienting of attention. *Ergonomics*, 39, 1119–1133.
- *Nougier, V., Stein, J.-F., & Azemar, G. (1990). Covert orienting of attention and motor preparation processes as a factor of success in fencing. *Journal of Human Movement Studies*, 19, 251–272.
- Nougier, V., Stein, J.-F., & Bonnel, A.-M. (1991). Information processing in sport and orienting of attention. *International Journal of Sport Psychology*, 22, 307–327.
- Overton, R. C. (1998). A comparison of fixed-effects and mixed (random-effects) models for meta-analysis tests of moderator variable effects. *Psychological Methods*, 3, 354–379.
- Pashler, H. (1999). *The psychology of attention*. Boston, MA: MIT Press.
- Posner, M., & Fan, J. Attention as an organ system. In J. R. Pomerantz (Ed.), *Topics in integrative neuroscience: From cells to cognition* (pp. 31–61). Cambridge, UK: Cambridge University press.
- Raudenbush, S. W. (1994). Random effects models. In H. M. Cooper, & L. V. Hedges (Eds.), *The handbook of research synthesis* (pp. 301–321). New York: Russell Sage.

- Raudenbush, S. W., & Bryk, A. S. (2002). *Hierarchical linear models: Applications and data analysis methods*. Thousand Oaks, CA: Sage.
- Rosenthal, R. (1995). Writing meta-analytic review. *Psychological Bulletin*, *118*, 183–192.
- Rotella, R. J., & Bunker, L. K. (1978). Field dependence and reaction time in senior tennis players (65 and over). *Perceptual and Motor Skills*, *46*, 585–586.
- Salthouse, T. A. (2004). What and when of cognitive aging. *Current Directions in Psychological Science*, *13*, 140–144.
- *Savelsbergh, G. J. P., Williams, A. M., Van Der Kamp, J., & Ward, P. (2002). Visual search, anticipation and expertise in soccer goalkeepers. *Journal of Sports Sciences*, *20*, 279–287.
- Schmidt, F. (1992). What do data really mean? Research findings, meta-analysis, and cumulative knowledge in psychology. *American Psychologist*, *47*, 1173–1181.
- Singer, R.N., (2000). Performance and human factors: Considerations about cognition and attention for self-paced and externally-paced events. *Ergonomics*, *43*, 1661–1680.
- *Starkes, J. L. (1987). Skill in field hockey: The nature of the cognitive advantage. *Journal of Sport Psychology*, *9*, 146–160.
- Starkes, J. L., Allard, F., Lindley, S., & O'Reilly, K. (1994). Abilities and skill in basketball. *International Journal of Sport Psychology*, *25*, 249–265.
- Starkes, J. L., & Ericsson, K. A. (2003). *Expert performance in sports: Advances in research on sport expertise*. Champaign, IL: Human Kinetics.
- Turatto, M., Benso, F., & Umiltà, C. (1999). Focusing of attention in professional women skiers. *International Journal of Sport Psychology*, *30*, 339–349.
- Viechtbauer, W. (2006). *MiMa: An S-Plus/R Function to Fit Meta-Analytic Mixed-, Random-, and Fixed-Effects Models* [Computer software and manual]. Retrieved from <http://www.wvbauer.com/>
- Viechtbauer, W. (2007). Moderator analysis in meta-analysis: A tutorial. *Journal of Psychology*, *215*, 104–121.
- *Voss, M. W., Neider, M. B., Carbonari, R., & Kramer, A. F. (2007). Unpublished Neuropsychological test Data Set Collected from June to December, 2007.
- Williams, A. M., Davids, K., & Williams, J. G. (1999). *Visual perception and action in sport*. London: E & FN Spon.