Psychological Bulletin

© 2021 American Psychological Association
ISSN: 0033-2909

2021, Vol. 147, No. 12, 1290–1308
https://doi.org/10.1037/bul0000355

The Role of Domain-Specific and Domain-General Cognitive Functions and Skills in Sports Performance: A Meta-Analysis

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Cognition plays a key role in sports performance. This meta-analytic review synthesizes research that examined the relationship between cognitive functions, skills, and sports performance. We identified literature by searching Cochrane Library, APA PsycINFO, PubMed, and Web of Science. We included studies conducted on competitive athletes, assessed cognitive prerequisites, and included performance measures related to the sport. Of the 9,433 screened records, 136 reports were included, containing 142 studies, 1,227 effect sizes, and 8,860 participants. Only 11 studies used a prospective study design. The risk of bias was assessed using the Risk of Bias Assessment Tool for Nonrandomized Studies. The multilevel meta-analysis showed a medium effect size for the overall difference in cognitive functions and skills, with higher skilled athletes scoring better than lower skilled athletes (Hedges' $g = 0.59$, 95% CI [0.49, 0.69]). The moderator analysis showed larger effect size for tests of cognitive decision-making skills ($g = 0.77$, 95% CI [0.6, 0.94]) compared to basic ($g = 0.39$, 95% CI [0.21, 0.56]) and higher cognitive functions ($g = 0.44$, 95% CI [0.26, 0.62]), as well as larger effect for sport-specific task stimuli compared to general ones. We report that higher skilled athletes perform better on cognitive function tests than lower skilled athletes. There was insufficient evidence to determine whether cognitive functions and skills can predict future sport performance. We found no evidence to support claims that tests of general cognitive functions, such as executive functioning, should be used by practitioners for talent identification or player selection.

Public Significance Statement
This meta-analysis indicates that testing cognitive functions or skills using sport-specific stimuli has the potential to differentiate between elite and nonelite athletes. There is, however, no evidence for the usefulness of using general, non-sport-specific cognitive function tests to predict future sport performance.

Keywords: cognitive functions, decision-making, expertise, sports level, sports performance

Supplemental materials: https://doi.org/10.1037/bul0000355.supp

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The authors declare no conflict of interest. The meta-analytic data and analysis code are shared at http://dx.doi.org/10.17605/OSF.IO/6QEKD.

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In sports, a combination of physiological capacities (e.g., anaerobic capacity), psychological characteristics (e.g., self-efficacy), and specific skills (e.g., technical and tactical) are essential to superior performance (Sarmento et al., 2018). Scientists studying the role of cognition in sports have mainly focused either on sport-specific cognitive skills (e.g., Starkes & Ericsson, 2003) or general cognitive functions (e.g., Voss et al., 2010). Both cognitive functions and skills are suggested to be factors associated with superior sport performance (e.g., Scharfen & Memmert, 2019). In this meta-analysis, we summarize current knowledge by undertaking a meta-analytical review of the role of cognition in sport performance. Moreover, we present a framework to provide a theoretically and methodologically sound structure to better understand the contribution of cognition to sport performance.

The Relationship Between Cognition and Performance in Sport: Current State-of-the-Art

Following the expert-performance approach (Starkes & Ericsson, 2003), researchers who have examined the relevance of *cognitive skills* in sports have mainly investigated differences in anticipation and decision-making between higher- and lower skilled athletes (e.g., Müller et al., 2006; Williams et al., 2002). These studies tend to represent key elements of the sport in the experimental design (i.e., presentation of stimuli and the type of response) to increase the representativeness of the methods employed (Araújo et al., 2007). Typical paradigms that fall within this description are the temporal occlusion paradigm (i.e., videos that are cut at a precise moment during an opponent's action) and the spatial occlusion paradigms (i.e., videos where specific parts of the action are hidden) to which participants are asked to decide how to "react." Responses can be provided either as option generation and selection (e.g., Musculus, 2018) or as an actual movement simulation (e.g., Farrow & Abernethy, 2002). Generally, higher skilled athletes outperform lower skilled ones on these sport-specific measures of cognitive skills (Mann et al., 2007; Travassos et al., 2013).

Another approach has been to investigate the relevance of *domain-general cognitive functions* in sport, mainly using non-sport-specific tasks. In these studies, standardized or generic tasks do not contain stimuli or responses specific to the sport. Prominent examples of non-sport-specific, general cognitive function tasks often used in cognitive research within sports are the Delis–Kaplan Executive Function System (D–KEFS; Vestberg et al., 2017), response-inhibition tasks such as the Go/No-go (Kida et al., 2005), and the Stop-Signal Task (Verburgh et al., 2014), as well as Trail Making Test and Stop-Signal Test (Huijgen et al., 2015; Verburgh et al., 2014). An earlier meta-analysis reported that athletes score better than nonathletes on these general, non-sport-specific cognitive function tasks (Voss et al., 2010). Since then, several studies have been published comparing higher skilled athletes to lower skilled ones, rather than to nonathletes, on general cognitive functions (Verburgh et al., 2014; Vestberg et al., 2017). Whereas higher skilled athletes outperformed their less skilled counterparts in inhibitory control (Huijgen et al., 2015; Verburgh et al., 2014) and cognitive flexibility (Huijgen et al., 2015), no differences were found for working memory (WM; Huijgen et al., 2015; Verburgh et al., 2014), meta-cognition (Huijgen et al., 2015), or orienting and executive attention (Verburgh et al., 2014). Yet, other researchers have suggested consistent differences in WM and design fluency tests between higher- and lower skilled athletes, leading to the conclusion that general cognitive tests can be used to predict sport performance (Vestberg et al., 2012, 2017). A recent meta-analysis supported this conclusion by showing that higher skilled athletes scored better on general cognitive functions (e.g., the D–KEFS, the Trail Making Test, or different measures of inhibition) when compared to control groups of both lesser skilled and non-athletes (Scharfen & Memmert, 2019). Although, the effects of general cognitive functions seem to be further qualified by moderators such as the type of cognitive function tested, the type of sport, the sporting level of the athletes, how the skill levels were defined, as well as the sex and the age of the athletes (Scharfen & Memmert, 2019; Voss et al., 2010).

An Operational Framework for Research on Cognition and Performance in Sport

Conceptually, the definitions and relations of the cognitive constructs and performance used in previous work in sports vary (e.g., Araújo et al., 2019). Therefore, this meta-analysis aims to theoretically structure the work focusing on the relationship between cognitive functions/skills and sport performance. To do so, we offer an operational framework by defining and relating the cognitive constructs following a task analysis. Consequently, we introduce theoretically relevant design moderators.

First, the cognitive constructs studied concerning sport performance need to be theoretically embedded. We differentiate between cognitive functions and cognitive skills because the relation to sport performance is established through different underlying mechanisms. In contrast to published reports that have treated cognitive functions and skills as integrated concepts (e.g., Takacs & Kassai, 2019), we view these concepts as separate and distinct. Skill is defined as "the ability to use one's knowledge effectively and readily in executing performance" (Tomporowski, 2003, pp. 1–2). Therefore, a skill is established through extended practice in a *specific* domain (e.g., Newell & Rosenbloom, 1981). Cognitive functions are general mechanisms at our disposal relevant to any goal-directed action in everyday life (Diamond, 2013; Miyake et al., 2000). They, however, require cognitive resources and effortful control (Diamond, 2013; Miyake et al., 2000). These functions need to be further differentiated into basic (or lower) and higher cognitive functions. Specifically, basic cognitive functions have their main neurological substrate in the primary sensory cortices, develop earlier in life, and are mainly required for direct interaction with tasks (Best & Miller, 2010; Paz-Alonso et al., 2013). Higher cognitive functions are "multidimensional executive and control processes characterized by being voluntary and highly effortful," which enable goal-directed planning before task interaction (Paz-Alonso et al., 2013, p. 1). From a neurological perspective, higher cognitive functions develop later, reflecting manifold changes in the brain, such as prefrontal cortex (PFC) maturation, specialization of certain areas (e.g., the middle and superior frontal gyrus regions), and the strengthening of white matter pathways (Paz-Alonso et al., 2013). According to this definition, an example of basic functions would be processing speed (Butzbach et al., 2019), whereas a prototypical example of higher cognitive functions would be executive functions (EFs; e.g., Miyake et al., 2000).

EFs are defined as "a set of general-purpose control processes that regulate one's thoughts and behaviors" (Miyake & Friedman, 2012,

p. 8) which are involved in the voluntary control of actions, thoughts, and emotions (Zelazo & Müller, 2010). Although widely studied over the last 20 years, there is no agreement on the number and definition of EFs (Martin & Failows, 2010). The most prominent and researched model of EFs is the factor-analytic model of Miyake et al. (2000), who isolated three separate but highly correlated EFs, namely WM updating, inhibitory control, and shifting (or cognitive flexibility). WM updating refers to the ability to update the information within one's WM and is different (even if correlated) from WM capacity, which refers to the individual differences in the limits of one's WM, often operationalized as the number of "mental units" an individual can simultaneously activate and operate on (e.g., Wilhelm et al., 2013). Inhibition refers to the ability to "override a strong internal predisposition or external lure, and instead do what's more appropriate or needed" (Diamond, 2013, p. 2). Multiple forms of inhibition have been studied, such as (a) resistance to interference, which allows selecting useful information and ignoring irrelevant stimuli; (b) cognitive inhibition, which takes place in WM; and (c) behavioral inhibition, which stops automatic but inefficient responses (Friedman & Miyake, 2004). Finally, shifting is defined as the ability to switch between mental sets (Miyake et al., 2000), which can be further detailed as (a) being able to move flexibly and efficiently from one task to another, (b) being able to change perspectives spatially or interpersonally, or (c) being able to adjust to changing demands of a task (Diamond, 2013). WM updating, inhibition, and shifting are considered "core" EFs, based on which higher order cognitive processes are activated, such as reasoning, problem-solving, and planning (Diamond, 2013). EFs are highly implicated in many aspects of life, from mental health to performance at school and job success (Diamond, 2013). From the early 2000s, many other theoretical approaches have defined and categorized EFs (see Müller & Kerns, 2015 for a detailed overview). However, WM updating, inhibition, and shifting have been the most extensively investigated EFs, and in the last 10 years, they have been studied concerning sports performance (e.g., Vestberg et al., 2017).

The second operational aspect that needs consideration is the nature of the task used to assess cognitive functions. In cognitive research regarding sports, the tasks used are either domain specific, meaning sport specific in this case (e.g., Mann et al., 2007), or domain general (e.g., Voss et al., 2010). For example, a decision-making assessment where soccer players are presented with videos of attacking situations from matches (e.g., Bennett et al., 2019) is *specific* to the sport domain. Whereas the Design Fluency Task (e.g., Ishihara et al., 2019) is not explicitly related to a domain but rather is domain *general*. Typically, domain-general tasks are used to measure basic or higher cognitive functions, whereas sport-specific tasks are used to assess cognitive skills. Although, this approach is not always true. For example, van de Water et al. (2017) designed a Badminton Reaction Inhibition Test, which used sport-specific stimuli to assess a general cognitive function, namely inhibition. In contrast, Gierczuk et al. (2018) measured Greco-Roman wrestlers processing speed with a sport-specific task. Therefore, we propose in our operational framework to differentiate stimuli and responses used in the respective tasks assessing either cognitive functions or skills as "general" (e.g., stimulus: arrows, response: button press) or sport specific (e.g., stimulus: soccer video scene, response: pass). This task analysis will help us close a gap in the literature and conceptually specify the domain-specific versus domain-general cognitive mechanisms underlying sport performance.

Beyond the construct definition and task analysis, it is conceptually relevant to refer to how cognition impacts sport performance. There is consensus that skill acquisition (learning) is a long and often deliberative process (e.g., Ericsson, 2014). This learning produces observable differences in intentional, sport-specific behavior (e.g., placing a pass, scoring a goal), which allows us to classify experts in sports by rank, leagues, and stages (e.g., Swann et al., 2015). Accordingly, researchers have well-established classifications in which expertise groups are defined based on observable performance criteria (e.g., Swann et al., 2015). Performance needs to be separated into cognitive performance, which can be observed in a cognitive skill or function task (e.g., reaction time in a Stroop test), and sporting performance (e.g., a timely pass to a team player in soccer), as captured by expertise levels or sport-specific behavior. Finally, for our main goal to operationally differentiate domain-general and domain-specific cognitive prerequisites, the task and the respective performance measures require us to separate whether sport-specific stimuli and/or responses are assessed or not. Therefore, we consider both the type of stimuli presented and the type of response captured as conceptually relevant moderators.

In the differentiation of basic and higher cognitive functions and skills, as well as in the classification of performance, it is evident that the athlete's age matters (Wattie et al., 2015). Previous work on the role of cognition in sport considered the age of the athletes as a moderator (Scharfen & Memmert, 2019). Although age-related development is seldom systematically addressed in sport research, previous work reported that basic and higher cognitive functions (Bisagno & Morra, 2018) as well as cognitive skills (Musculus et al., 2019) undergo different developmental trajectories, which are likely due to physiological and frontal lobe changes (e.g., Blows, 2003; Huizinga et al., 2006). Therefore, to better understand the cognitive processes involved in sport performance, age needs to be considered as a moderator. In this meta-analysis, we differentiated age according to the age structure of the sport system and classic developmental classification (i.e., childhood, adolescence, adulthood; cf. Shaffer & Kipp, 2014).

Relatedly, the study design has important conceptual consequences to better understand the mechanisms underlying the cognition–performance relation. Whether the study design applied is cross sectional or prospective determines which relation between cognition and performance can be inferred. In a cross-sectional design, in which cognitive tasks and sport performance are assessed simultaneously, an *association* at that specific point in time can be captured. Although, no time-ordered relation can be inferred. Whether performance in cognitive tasks predicts future sport performance can only be tested in prospective designs, in which sport performance is measured later than cognitive performance. Therefore, in our meta-analysis, we operationally consider the type of study design employed as a conceptually relevant moderator to better scrutinize the cognition–performance relationship.

The relationship between different cognitive functions/skills and sports performance is relevant from both theoretical and applied perspectives. The conclusions presented in recent studies that general cognitive tests can predict sport performance has led prematurely to recommendations that such measures may be used in applied settings (Sakamoto et al., 2018; Vestberg et al., 2012). More specifically, it has driven the commercialization of products measuring general cognitive function, such as EFs, to potentially help clubs identify and select athletes into systematic elite training programs that involve the selection and identification of "talented" youth athletes (Kittelberger, 2018; Mann et al., 2017). However, the validity of this methodology has been questioned (Beavan et al., 2020; Renshaw et al., 2019).

To our knowledge, no published review or meta-analysis has focused on how a broad range of both cognitive functions and cognitive skills are related to sport performance while systematically considering the other conceptually relevant moderators introduced above (i.e., type of stimuli, type of response, age, and study design). Furthermore, existing meta-analyses on general cognitive functions have included studies comparing athletes to nonathletes rather than different levels of skilled athletes. Therefore, the purpose of this meta-analytic review is to synthesize research that has examined the relationship between cognitive functions/skills and sports performance across a wide range of cognitive tasks but excluding visual ability or brain activity. We investigate differences in cognitive test performance (e.g., scores and/or response time) between competitive athletes of different skill levels. Moreover, we test whether this difference is influenced by the following moderators: the underlying cognitive construct (basic cognitive function vs. higher cognitive function vs. cognitive decision-making skill), the sport-specificity of stimuli used in the cognitive tasks, and sport-specificity of responses used in the cognitive tasks. In addition, we test the effects of the age of athletes, which is often confounded when analyzing differences between higher skilled and lower skilled athletes. Finally, we examine the impact of the study design employed (see Table 1 for an overview of moderators).

Method

The review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021).

Literature Search Strategy

Literature searches were conducted using four electronic databases: Cochrane Library; APA PsycINFO; PubMed; and Web of Science Core Collection (citation indexes: Science Citation Index Expanded [SCI-EXPANDED], Social Sciences Citation Index [SSCI], Emerging Sources Citation Index [ESCI], Conference Proceedings Citation Index - Science [CPCI-S], Conference Proceedings Citation Index - Social Science & Humanities [CPCI-SSH], Arts & Humanities Citation Index [A&HCI], Book Citation Index - Social Science & Humanities [BKCI-SSH], Book Citation Index - Science [BKCI-S]). The original searches were undertaken on December 12, 2019, and were updated on January 19, 2022. The search term included three parts: one with keywords related to the cognitive function, including cognitive, executive function, attention, memory, inhibition, anticipation, decision-making, reaction time, and variations; one related to sport or athlete; and a third one related to expertise, elite, talent. No limits on publication date, publication status, or language were placed. For the complete search strategy, see Supplemental Materials Table S1. In addition, experts in the field were consulted, and the reference lists of all the included articles and previous reviews were screened for eligible articles (Mann et al., 2007; Russo & Ottoboni, 2019; Scharfen & Memmert, 2019; Travassos et al., 2013; Voss et al., 2010).

Selection Criteria

An article was considered if it met the following criteria (a) was conducted on athletes involved in competitive sport; (b) assessed cognitive function of the athletes; (c) included performance measures related to the sport of the athletes (e.g., groups of athletes from higher and lower divisions, number of goals scored during the

Table 1
Overview and Definition of Moderators

Level	Definition
	Cognitive construct
Basic cognitive functions	Cognitive functions requiring mainly one cognitive capacity and developing first are considered “basic” cognitive functions, for example, functions like processing speed, attention, and short-/long-term memory.
Higher cognitive functions	Functions that coordinate more than one basic cognitive function and/or involve more than one cognitive capacity are referred to as “higher” cognitive functions, for example, executive functions (namely working memory capacity and updating, inhibition, and shifting). Such higher functions are often required to solve complex sports tasks.
Cognitive decision-making skills	Skills to choose among action options, comprising judgment, decision-making, and anticipation tasks.
	Stimuli
General	Stimuli not displaying sports movement/movement sequences and/or a sport situation, but schematic presentations of sport situation fall in this category.
Sport-specific	Stimuli displaying a sports movement/movement sequences and/or a sport situation, for example, pictures or videos, but not the schematic presentations of a sport situation.
	Response
General	Response formats displaying sport movements/situations but still asking the participants to draw/mark/highlight their response, for example, by marking player positions, possible options how to play or else, are not considered sport specific because the response itself does not involve the specific movement
Sport-specific	Responses requiring the participants to perform a movement as if they were in a real sport situation.
	Age group
Late childhood	Average age of athletes is 8–13 years.
Adolescence	Average age of athletes is 14–17 years.
Adulthood	Average age of athletes is over 18 years.
	Study design
Cross-sectional	Cognitive and performance level data are collected at or around the same point in time.
Prospective	Cognitive data are clearly collected before the collection of performance level data.

season, selected or not into academy); and (d) compared athletes competing within the same sport (e.g., soccer players from first division vs. soccer players from second division). We excluded studies if (a) the lower skilled group in the study had less than 1 year of experience in the sport or did not engage competitively or (b) the dependent variables were not cognitive variables but visual ability (e.g., gaze behavior), brain activity (e.g., functional magnetic resonance imaging [fMRI]), pure reaction time with minimal motor action (e.g., button pressing) or procedural knowledge. These criteria ensured that the sport performance of experienced athletes was compared and that cognitive processes were captured on a behavioral level.

After removing duplicate records, two authors (AK & AP-F) independently screened titles and abstracts, with an agreement of 99%. For the 83 records where the authors disagreed, a third author (AI) was consulted, and a consensus was reached by discussion. After screening, the full-text reports were assessed for eligibility independently by the same two authors (AK & AP-F), with an agreement of 90%. For the 27 reports where the authors disagreed, a third author (AI) was consulted, and a consensus was reached by discussion. Records in Spanish, Portuguese, German, and French were translated by native or fluently speaking co-authors. Records in Chinese and Japanese were translated using Google Translate.

Data Extraction and Classification

For all measures in the included studies, we classified the underlying cognitive construct, the sport-specificity of stimuli used in the cognitive tasks, sport-specificity of responses used in the cognitive functions, the age of the athletes, and study design employed. The definition of the levels for each moderator can be seen in Table 1.

In detail, the cognitive construct underlying the relation between cognitive performance and the cognitive construct assessed was classified as either basic cognitive functions, higher cognitive functions, or cognitive decision-making skills, based on definitions by Best and Miller (2010). Cognitive tasks relying mainly on cognitive capacity or processing efficiency (e.g., attention, short-term memory, processing speed) were classified as basic cognitive functions. Tasks that involve several cognitive capacities or require coordinating multiple basic cognitive functions (e.g., WM capacity, inhibition, and shifting) were classified as higher cognitive functions. Tasks that required a perceptual judgment and an action choice (e.g., multiple choice based on stimuli and anticipation) were classified as cognitive decision-making skills. The stimuli used in the cognitive tasks were classified as sport specific if they displayed a sport movement, sport movement sequence, or sport situation (e.g., pictures or videos but not the schematic presentations of a sport situation) or otherwise as general. The responses used in the cognitive tasks were classified as being sport specific if they required the participants to perform a movement as if they were in an in situ sport context and otherwise as general. The average age of the athletes was used to categorize the studies into late childhood (8–12 years old), adolescence (13–17 years old), or adulthood (over 18 years old). The age division was operated concerning physiological changes that occur during development, namely the second phase of plasticity and the growth of frontal lobe areas during adolescence occurring between 13 and 18 years (e.g., Blows, 2003; Huizinga et al., 2006). This distinction is superimposable with Shaffer and Kipp (2014) stages of development. Finally, the design used was classified as prospective if the cognitive data were collected before collecting sport performance data or cross sectional if cognitive and sport performance data were collected at or around the same point in time.

Two authors (LM & EB) classified the studies independently, who reached a total agreement in 82% of the studies and 93% of the classified dimensions, three for each study. For the dimensions the raters did not agree on, they subsequently jointly discussed the disparity, reaching a consensus on 13 dimensions. For the 20 dimensions, where the authors could not reach an agreement were later discussed with a third author (MR) until consensus was reached on all dimensions of all studies.

All results meeting the inclusion criteria in each study were extracted, including group mean and standard deviation, proportions, correlation coefficients, t statistics, and F statistics. A sensitivity analysis revealed no influence of the type of measure on the effect size, $F(4, 1.9) = 1.3$, $p = .481$; see method below. Nine emails were sent to the corresponding authors of articles where necessary information to calculate standardized effect sizes was missing. Three authors responded.

Risk of Bias

The Risk of Bias Assessment Tool for Nonrandomized Studies (Kim et al., 2013) was used to assess the risk of bias in six domains: (a) Selection of participants, (b) Confounding variables, (c) Measurement of exposure, (d) Blinding of outcome assessments, (e) Incomplete outcome data, and (f) Selective outcome reporting. One author (AK) assessed the risk of bias for each included study accordingly and discussed any doubts with a second author (AP-F) until consensus was reached.

Analysis

We converted the statistics to Hedges' g, based on Lipsey and Wilson (2001). The summary of study characteristics and moderator values were presented separately for each cognitive construct. As the studies varied significantly in design and multiple effect sizes were extracted, we used three-level meta-analytical models with cluster–robust variance estimation (Fernández-Castilla et al., 2021; Pustejovsky & Tipton, 2021), with effect sizes clustered within each study. All models were fitted using the R package metaphor, and the robust variance was estimated using the clubSandwich package (Pustejovsky, 2021; Viechtbauer, 2010). In the three-level models, random effects for study (Level 2) and effect size (Level 1) represent the estimates of between-study ($\tau^2_{\text{between-study}}$) and within-study ($\tau^2_{\text{within-study}}$) heterogeneity variance, respectively.

After performing the overall meta-analysis, we performed the prespecified moderator analyses using models containing one moderator at a time to test for differences in effect size between the different cognitive constructs. In the next step, we fitted separate moderator models for the type of stimuli, type of response, age group, and study design, including cognitive construct in all because the data revealed interactions between the cognitive constructs and the other moderators. The missing combination of levels between the different moderators did not allow us to perform a full moderator analysis, including all in the same model. We performed a post hoc subgroup analysis for each combination of cognitive construct and task specificity, reflecting a combination of the stimuli presented and the responses captured. The task specificity was classified as "general" if both stimuli and response were general, "mixed" if either the stimuli or response was specific, and "specific" if both stimuli and response were specific.

For all fitted moderator models, the $\tau^2_{\text{between-study}}$ were used to see if including moderators reduced the between-study heterogeneity. In addition, the post hoc subgroup model with both cognitive constructs and task specificity was compared to the moderator model, including either cognitive construct and stimuli or cognitive construct and response using the corrected Akaike information criterion (AIC; Viechtbauer, 2010).

At last, we tested the results for statistical robustness by conducting sensitivity analyses, considering potential publication bias, and providing common language effect sizes. We performed sensitivity analyses for the type of measure of effect size, publication year, and risk of bias domains by testing their moderator effect in the three-level model.

We used Egger's regression type test to test for potential publication bias, using a three-level model with cluster–robust variance estimation (Fernández-Castilla et al., 2019; Rodgers & Pustejovsky, 2021). The modified measure of precision proposed by Pustejovsky and Rodgers (2019) was used to reduce Type I error due to artificial correlations between the effect size estimates and their standard error. The test was run with all effect sizes and separately for each cognitive construct.

We present the estimated effect sizes expressed as common language effect sizes, representing the probability that a randomly selected participant from the higher skilled group would score better on the cognitive task than a randomly selected participant from the lower skilled group (McGraw & Wong, 1992; Ruscio, 2008). The common language effect size provides a more practically relevant measure of the effect compared to the standardized mean difference (Brooks et al., 2014).

We used a significance level of $\alpha = 0.05$ and presented corresponding 95% confidence intervals (CI). F tests use Hotelling's T^2, and t tests use Satterthwaite's degrees-of-freedom approximation. All analyses were made in R Version 4.1.2.

Transparency and Openness

We followed PRISMA reporting guidelines for this review. The meta-analytic data and analysis code are shared at the Open Science Framework (OSF) repository available at http://dx.doi.org/10.17605/OSF.IO/6QEKD.

Results

Literature Search

A complete flowchart of the selection process, including reasons for exclusion, can be seen in Figure 1. We identified 12,641 records through database searches. After duplicate removal, the title and abstract of 9,416 records were screened, from which the 292 full-text reports were reviewed. An additional 17 full-text reports from other sources were reviewed, and nine were included in the review. A total of 136 reports, containing 142 studies and 1,227 effect sizes were included.

Study Characteristics

A summary of study characteristics can be seen in Table 2. Characteristics of all individual studies can be seen in Supplemental Materials Tables S2–S4 for studies containing basic cognitive functions, higher cognitive functions, and cognitive decision-making, respectively. The included studies were published between 1995 and 2021. There was no significant effect of publication year on the effect size estimates, $t(29.9) = 0.1$, $p = .911$. The studies included participants from a total of 39 sports. The most common sports were soccer (studies $k = 43$ [27%], participant $n = 3{,}135$), tennis ($k = 13$ [8%], $n = 428$), rugby ($k = 12$ [8%], $n = 736$), basketball ($k = 11$ [7%], $n = 754$), handball ($k = 11$ [7%], $n = 446$), and baseball ($k = 10$ [6%], $n = 871$). Most studies came from Europe, North America, or Oceania ($k = 131$ [92%], $n = 7{,}845$). The most common countries were United Kingdom ($k = 28$ [19%], $n = 2{,}136$), Australia ($k = 24$ [16%], $n = 1{,}575$), Germany ($k = 20$ [13%], $n = 1{,}204$), Netherlands ($k = 10$ [7%], $n = 543$), and USA ($k = 10$ [7%], $n = 874$).

Altogether, in 84 (59%) of the studies, no information was provided about funding, and 19 (13%) reported that they had received no funding. Of the 39 (27%) studies reporting that funding was received, none reported funding from companies commercializing tests of cognitive functions. Six studies reported funding from sports governing bodies (Duncan et al., 2018; Gorman et al., 2011; Lu et al., 2021; Müller et al., 2010; O'Connor et al., 2016; Rosalie & Müller, 2013).

Nineteen studies reported using a commercial test system to measure basic and higher cognitive functions, while no study specified using a commercial system for measuring cognitive decision-making skills. The systems used can be seen in Table 3.

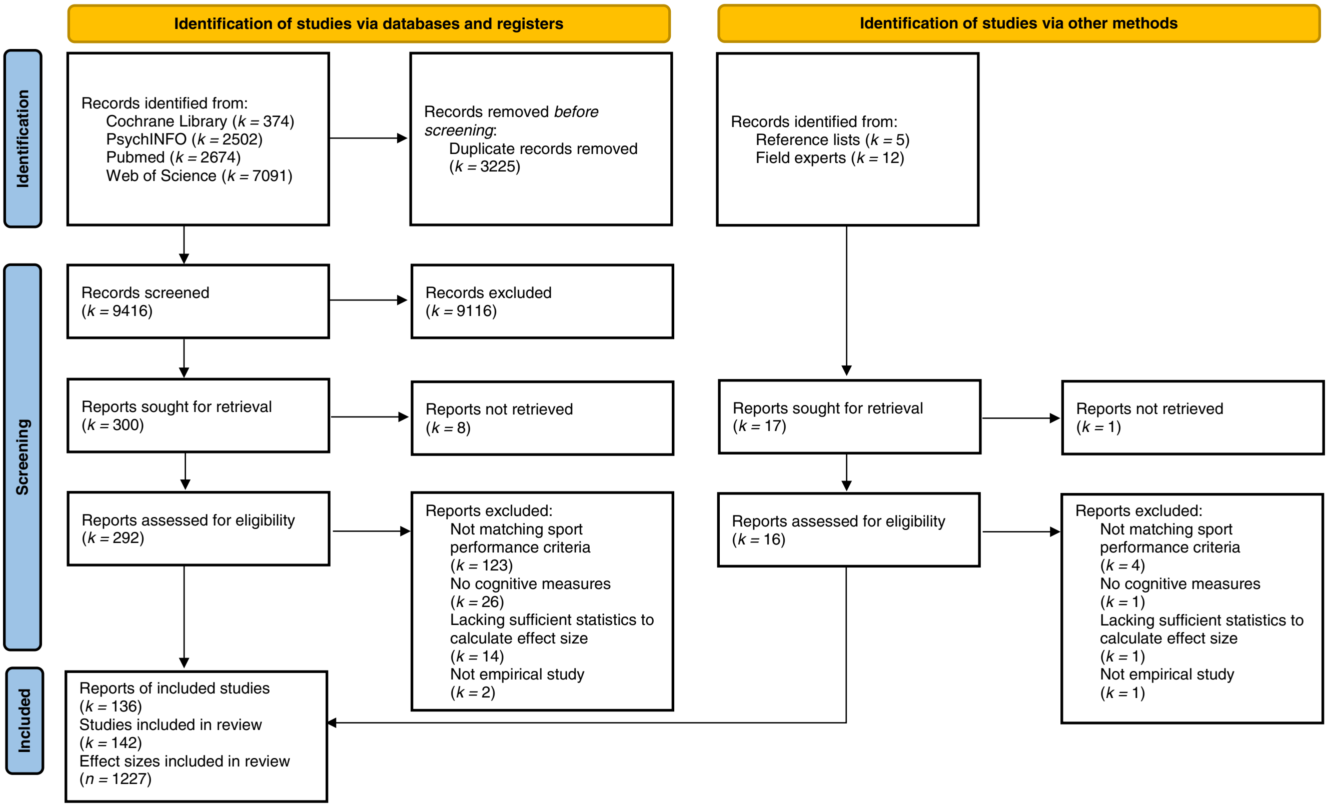
Cognitive Tasks

Of all included articles, 57 (40%) contained measures of basic cognitive function (participants $n = 4{,}276$), 39 (27%) contained measures of higher cognitive function ($n = 3{,}393$), and 80 (56%) contained measures of cognitive decision-making skill (participants $n = 4{,}145$), see Table 2. A total of 30 studies (21%) contained data for multiple cognitive constructs, 18 (13%) included basic and higher cognitive functions, five (4%) included basic cognitive functions and cognitive decision-making skills, three (2%) higher cognitive functions and cognitive decision-making skills, and five (4%) all three constructs.

The most common type of tasks used to measure basic cognitive functions were different versions of visual reaction time, used in 12 (9%) studies (Bahia Loureiro & de Freitas, 2012; Chung & Ng, 2012; Gierczuk et al., 2018; Hüttermann et al., 2019; Kajtna et al., 2012; Laby et al., 2018; Millard et al., 2020; Vänttinen et al., 2010; Vaughan & Laborde, 2021; Vestberg et al., 2017, 2020; Whitaker et al., 2020 [Study 2]). The most common tasks used to measure higher cognitive functions were the design fluency test (9 studies, 7%), Trail Making Test (9 studies, 7%), and Stroop test (8 studies, 6%). There was considerable overlap in the use of these tests in the articles, with two studies (2%) including all three (Elferink-Gemser et al., 2018; Vestberg et al., 2012), seven studies (5%) including two of them (Alarcón et al., 2017; Heilmann, 2021; Huijgen et al., 2015; Lundgren et al., 2016; Sakamoto et al., 2018; Vestberg et al., 2017, 2020), and four studies (3%) only one of the three tests (Han et al., 2011; Holfelder et al., 2020; Ishihara et al., 2019; Kruger et al., 2019). The most common task types for cognitive decision-making skills were video-based temporal occlusion tests, used in 56 articles (39%).

Figure 1

Flow of Study Reports Into the Research Synthesis



Note. See the online article for the color version of this figure.

Study Design

Of the included studies, 11 (8%) used a prospective design in at least part of the study (participants $n = 1{,}154$). Of these, three used participants who were in late childhood with a total of 436 athletes (de Joode et al., 2021; Ishihara et al., 2019; Sakamoto et al., 2018), four used athletes in adolescence with a total of 272 participants (de Joode et al., 2021; Joseph et al., 2021; Murr et al., 2021; O'Connor et al., 2016), and eight in adulthood with a total of 565 participants (Gabbett et al., 2011; Hagyard et al., 2021; Lundgren et al., 2016; Morris-Binelli et al., 2018; Vestberg et al., 2012).

Three of the prospective studies (participants $n = 714$) had a follow-up less than or around 1 month later, testing how cognitive test scores measured before the start of the season related to their probability of being selected into the team for that same season (Gabbett et al., 2011; Joseph et al., 2021; O'Connor et al., 2016; Sakamoto et al., 2018). Five studies (participants $n = 295$) had a follow-up of 6 months to 2.5 years, testing how cognitive test scores related to in-game performance over the following one to two seasons (Lundgren et al., 2016; Morris-Binelli et al., 2018; Vestberg et al., 2012), the coaches rating at the end of the season (Hagyard et al., 2021), or their competitive ranking 18 months later (Sakamoto et al., 2018). Two studies (participants $n = 99$) had a follow-up of over 3 years, testing how cognitive test scores relate to their chance of being selected into a youth national team over the next 3 years (Murr et al., 2021) and of becoming an elite athlete 7 years later (de Joode et al., 2021).

Two prospective studies (participants $n = 528$) contained measures of basic cognitive functions, using reactive agility (Gabbett et al., 2011) and Stroop tests (Sakamoto et al., 2018). Five studies (participants $n = 573$) contained measures of higher cognitive functions, using design fluency test (Ishihara et al., 2019; Lundgren et al., 2016; Sakamoto et al., 2018; Vestberg et al., 2012), Trail Making Test (Vestberg et al., 2012), a Stop-Signal Task (Hagyard et al., 2021). Five studies (participants $n = 390$) contained measures of cognitive decision-making skills using video-based temporal occlusion tests (de Joode et al., 2021; Joseph et al., 2021; Morris-Binelli et al., 2018; Murr et al., 2021; O'Connor et al., 2016).

In total, we identified three studies that tested the ability to use cognitive tasks to predict performance or success several years later (de Joode et al., 2021; Ishihara et al., 2019; Murr et al., 2021).

Risk of Bias

The number of studies with a low, unclear, and high risk of bias in each of the six domains of bias can be seen in Table 4. Overall, 84 (66%) of the studies showed a high risk of bias due to confounding variables and 35 (27%) due to the selection of participants. In the

Table 2
Summary of Study Characteristics

Variable	Total	Basic cognitive function	Higher cognitive function	Cognitive decision-making skills
Number of studies[a]	142	57	39	80
Number of effect sizes	1,227	275	320	632
Number of participants	8,860	4,276	3,393	4,145
Number of females[b]	1,442 (16%)	623 (15%)	696 (21%)	575 (14%)
M_{age} (years)	19.0	18.7	18.4	19.7
First publication year	1995	1995	2005	1995
Publication year median	2016	2015	2017	2014.5
Type of stimuli				
General	51 (36%)	36 (63%)	31 (79%)	3 (4%)
Specific	80 (56%)	13 (23%)	7 (18%)	70 (88%)
Both	11 (8%)	8 (14%)	1 (3%)	7 (9%)
Type of response				
General	110 (77%)	47 (82%)	37 (95%)	55 (69%)
Specific	27 (19%)	6 (11%)	0 (0%)	21 (26%)
Both	5 (4%)	4 (7%)	2 (5%)	4 (5%)
Combined stimuli and response				
General	57 (36%)	40 (62%)	32 (82%)	5 (6%)
Mixed	75 (47%)	21 (32%)	7 (18%)	57 (67%)
Specific	27 (17%)	4 (6%)	0 (0%)	23 (27%)
Age group[c]				
Late Childhood	13 (9%)	6 (10%)	5 (13%)	6 (7%)
Adolescence	25 (17%)	5 (6%)	9 (23%)	15 (18%)
Adulthood	109 (74%)	57 (67%)	25 (64%)	61 (74%)
Study design				
Cross-sectional	131 (92%)	54 (95%)	74 (92%)	32 (82%)
Prospective	5 (4%)	2 (4%)	4 (5%)	3 (8%)
Both	6 (4%)	1 (2%)	4 (10%)	2 (2%)
Continent[d]				
Africa	2 (1%)	2 (3%)	1 (3%)	0 (0%)
Asia	10 (7%)	5 (8%)	6 (15%)	2 (2%)
Europe	97 (67%)	43 (73%)	29 (74%)	51 (64%)
North America	10 (7%)	3 (5%)	0 (0%)	7 (9%)
Oceania	24 (17%)	5 (8%)	3 (8%)	20 (25%)
South America	1 (1%)	1 (2%)	0 (0%)	0 (0%)

[a] Thirty of the studies contained data for multiple cognitive constructs (basic cognitive function—higher cognitive function, $k = 18$; basic cognitive function—cognitive decision-making skills, $k = 5$; higher cognitive function—cognitive decision-making skills, $k = 3$; all three constructs, $k = 4$). [b] Twenty-seven studies did not specify gender of participants. [c] Four studies contained multiple age groups (late childhood—adolescence, $k = 2$; adolescence—adulthood, $k = 1$; all three age groups, $k = 1$). [d] One study contained participants from Europe, North America, and Oceania.

other domains, 0%–4% of the studies showed a high risk of bias. We see similar patterns of bias in studies measuring each cognitive construct. The sensitivity analysis revealed no effect of risk of bias on effect size estimate in any dimension, selection of participants: $F(2, 33.0) = 1.3$, $p = .279$; confounding variables: $F(1, 117) = 1.7$, $p = .198$; blinding of outcome assessments: $F(1, 1.0) = 6.3$, $p = .236$; incomplete outcome data: $F(2, 10.4) = 0.8$, $p = .464$; selective outcome reporting: $F(2, 3.2) = 1.6$, $p = .296$. No sensitivity analysis was run for the measurement of exposure as all studies had the same classification.

Table 3
Commercial Cognitive Tests Used in the Literature

Cognitive test	Studies
Cambridge Neuropsychological Test Automated Battery (CANTAB)	Hagyard et al. (2021), Vaughan et al. (2019, Vaughan and Edwards (2020), Vaughan et al. (2021), and Vaughan and Laborde (2021)
Cognifoot	Hicheur et al. (2017)
CogState Sports	Vestberg et al. (2020) and Vestberg et al. (2017)
Delis–Kaplan Executive Function System (D–KEFS)	Alarcón et al. (2017), Elferink-Gemser et al. (2018), Huijgen et al. (2015), Ishihara et al. (2019), Lundgren et al. (2016), Sakamoto et al. (2018), Vestberg et al. (2012), Vestberg et al. (2020), and Vestberg et al. (2017)
Test2Drive system	Przednowek et al. (2019)
Wechsler Intelligence Scale for Children III (WISC-III)	Verburgh et al. (2016a)
Vienna Test System	Baláková et al. (2015)
Wisconsin Card Sorting Test (WCST)	Han et al. (2011)

Table 4
Risk of Bias

Risk of bias	Selection of participants	Confounding variables	Measurement of exposure	Blinding of outcome assessments	Incomplete outcome data	Selective outcome reporting
			Basic cognitive functions			
Low	39 (16%)	21 (9%)	57 (23%)	56 (23%)	17 (7%)	56 (23%)
Unclear	3 (7%)	0 (0%)	0 (0%)	1 (2%)	40 (91%)	0 (0%)
High	15 (29%)	36 (69%)	0 (0%)	0 (0%)	0 (0%)	1 (2%)
			Higher cognitive functions			
Low	23 (14%)	16 (10%)	39 (23%)	37 (22%)	13 (8%)	39 (23%)
Unclear	4 (14%)	0 (0%)	0 (0%)	2 (7%)	23 (79%)	0 (0%)
High	12 (32%)	23 (61%)	0 (0%)	0 (0%)	3 (8%)	0 (0%)
			Cognitive decision-making skills			
Low	57 (17%)	37 (11%)	80 (23%)	78 (23%)	16 (5%)	77 (22%)
Unclear	8 (11%)	0 (0%)	0 (0%)	2 (3%)	62 (86%)	0 (0%)
High	15 (24%)	43 (68%)	0 (0%)	0 (0%)	2 (3%)	3 (5%)
			Total			
Low	94 (15%)	58 (10%)	142 (23%)	140 (23%)	38 (6%)	138 (23%)
Unclear	13 (11%)	0 (0%)	0 (0%)	2 (2%)	99 (87%)	0 (0%)
High	35 (27%)	84 (66%)	0 (0%)	0 (0%)	5 (4%)	4 (3%)

Publication Bias

There was a significant relationship between effect size estimate and precision, 0.80, $SE = 0.34$, $t(32.9) = 2.4$, $p = .025$, indicating possible publication bias. Yet, the separate tests for each cognitive construct did not show evidence of publication bias in any of them, basic cognitive functions: 0.06, $SE = 0.66$, $t(16.6) = 0.1$, $p = .933$; higher cognitive functions: 0.54, $SE = 0.43$, $t(11.1) = 1.25$, $p = 236$; cognitive decision-making skills: 0.92, $SE = 0.69$, $t(11.6) = 1.6$, $p = .144$. We present funnel plots for all included studies, as well as by cognitive construct, in Figure 2.

Meta-Analysis

The overall effect size estimate (Hedges' g) for all measures of cognition was 0.59, 95% CI [0.49, 0.69], indicating that higher skilled athletes outperformed lower skilled athletes on cognitive tasks. The between-study heterogeneity was $\tau^2_{\text{between-study}} = 0.30$, 95% CI [0.22, 0.42] and the within-study heterogeneity $\tau^2_{\text{within-study}} = 0.14$, 95% CI [0.12, 0.16]. The effect size estimates for each cognitive construct and each combination of cognitive construct and each of the other moderators are shown in Table 5. Forrest plots can be seen in Supplemental Materials Figures S1–S3 for basic cognitive functions, higher cognitive functions, and cognitive decision-making, respectively.

Cognitive Constructs

The estimated effect size is significantly positive for all three cognitive constructs, basic cognitive functions $g = 0.39$, 95% CI [0.21, 0.56], $t(63.1) = 4.4$, $p < .001$; higher cognitive functions $g = 0.44$, 95% CI [0.26, 0.62], $t(51.2) = 4.9$, $p < .001$; cognitive decision-making skills $g = 0.77$, 95% CI [0.6, 0.94], $t(70.8) = 9.2$, $p < .001$). Higher skilled athletes, on average, score higher than lower skilled athletes in tests of all three cognitive constructs (Table 5).

The estimated effect size for cognitive decision-making skills was significantly larger than for both basic cognitive functions, $t(39.7) = 3.1$, $p = .011$, and higher cognitive functions, $t(39.7) = 2.7$, $p = .015$, whereas there was no significant difference between basic and higher cognitive functions, $t(18.6) = 0.4$, $p = .397$. The chance that a randomly selected athlete from a higher skilled group will outscore a randomly selected athlete from a lower skilled group is on tasks of basic cognitive functions 61% (95% CI [56%, 65%]), on tasks of higher cognitive functions 62% (95% CI [57%, 67%]), and on tasks of cognitive decision-making skills 71% (95% CI [67%, 75%]). Including cognitive construct in the meta-analysis slightly lowered the between-study heterogeneity ($\tau^2_{\text{between-study}} = 0.28$, 95% CI [0.20, 0.39]).

Stimuli

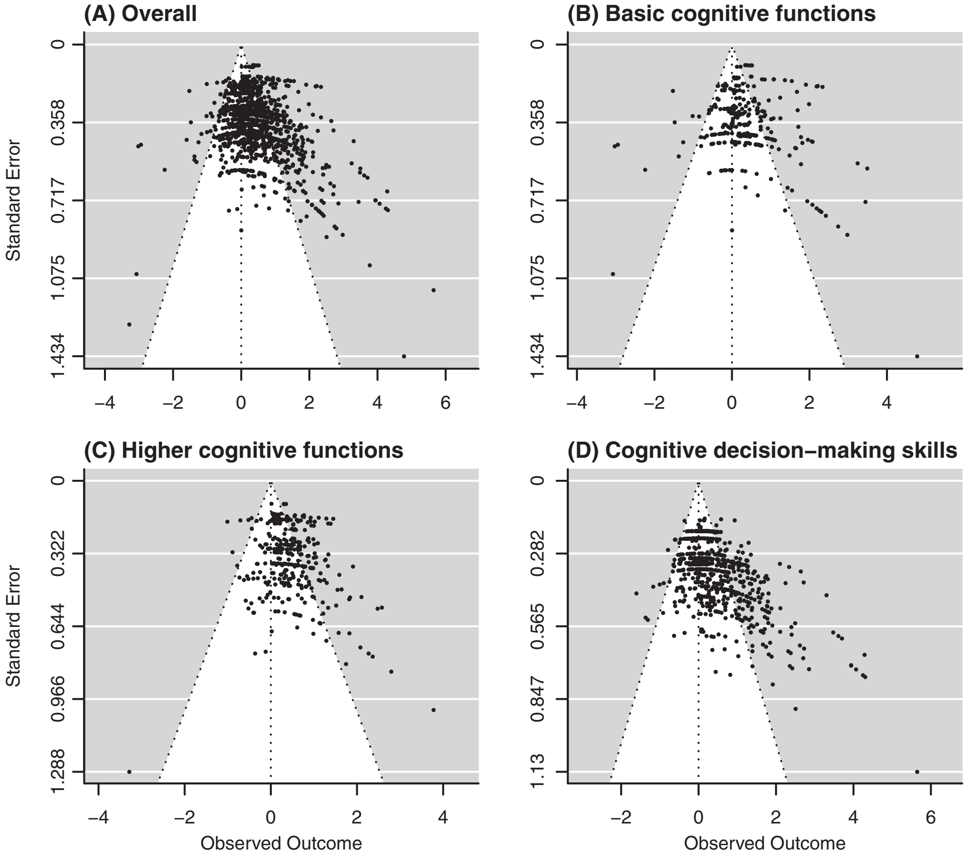
Overall, higher skilled athletes outscored lower skilled athletes more on tasks with specific compared to general stimuli, g specific stimuli—g general stimuli = 0.37, 95% CI [0.09, 0.65], $t(31.6) = 2.7$, $p = .011$, when adjusting for the effect of cognitive construct (i.e., basic cognitive functions, higher cognitive functions, and cognitive decision-making skills). We observed that the estimated effect sizes for specific stimuli was 1.8–3.2 times higher than for general stimuli for each cognitive construct (Table 5). The respective difference between specific and general stimuli was significant for cognitive decision-making skills, $t(4.77) = 4.3$, $p = .026$, but not for basic, $t(22.8) = 1.5$, $p = .147$) or higher cognitive functions, $t(9.6) = 1.8$, $p = .147$). Including stimuli, in addition to cognitive construct, in the meta-analysis did not change the between-study heterogeneity ($\tau^2_{\text{between-study}} = 0.28$, 95% CI [0.21, 0.39]).

Response

There was no significant difference in estimated effect size between general and specific response, g specific response—g general response = 0.25, 95% CI [−0.05, 0.56], $t(17.7) = 1.8$, $p = .097$) when at the same time adjusting for the effect of cognitive construct (i.e., basic cognitive functions, higher cognitive functions, and cognitive decision-making skills). We observed that the estimated effect sizes for specific responses were 1.4 and 1.5 times larger than general stimuli within basic cognitive functions and

Figure 2

Funnel Plots for (A) All Effect Sizes and (B–D) Each Cognitive Construct



Note. Positive effect size indicates that higher skilled athletes outscore lower skilled athletes in cognitive tasks. Dependence between effect sizes clustered within the same study is not represented in the figures.

cognitive decision-making skills, respectively (Table 5). Although, the difference between specific and general responses was not significant for basic cognitive functions, $t(4.3) = 0.6$, $p = .600$, nor for cognitive decision-making skills, $t(25.7) = 1.7$, $p = .198$). No studies tested higher cognitive functions in conjunction with specific responses. Including response, in addition to cognitive construct, in the meta-analysis did not change the between-study heterogeneity ($\tau^2_{\text{between-study}} = 0.28$, 95% CI [0.20, 0.39]).

Age Group

There was no significant difference in estimated effect sizes between the different age groups, $F(2, 9.3) = 2.5$, $p = .135$, when adjusting for the effect of the cognitive construct. Yet, we found a general trend toward larger effect sizes in older age groups (Table 5). Including age group, in addition to cognitive construct, in the meta-analysis slightly increased the between-study heterogeneity ($\tau^2_{\text{between-study}} = 0.29$, 95% CI [0.20, 0.40]).

Study Design

There was no significant difference in estimated effect size between cross-sectional and prospective response, g prospective —g cross-sectional $= -0.15$, 95% CI [−0.38, 0.07], $t(5.75) = -1.6$, $p = .149$, when adjusting for effect of cognitive construct. Including study design, in addition to cognitive construct, in the meta-analysis slightly lowered the between-study heterogeneity ($\tau^2_{\text{between-study}} = 0.27$, 95% CI [0.20, 0.38]).

Post Hoc Subgroup Analysis

We conducted a subgroup analysis for each combination of cognitive construct and task specificity, considered as general if both stimulus and response were general, mixed if either the stimulus or response was specific, and specific if both stimulus and response were specific. We found a general trend toward larger effect sizes the more complex the cognitive constructs and the more specific the tasks were. The estimated effect sizes, together with the chance that a randomly higher skilled athlete will outscore a randomly selected lower skilled athlete, are reported in Figure 3.

The subgroup model showed similar between-study heterogeneity ($\tau^2_{\text{between-study}} = 0.28$, 95% CI [0.20, 0.39]) and within-study heterogeneity ($\tau^2_{\text{within-study}} = 0.14$, 95% CI [0.12, 0.16]) compared to the model including cognitive constructs. The subgroup model showed a slightly better model fit (corrected AIC = 2,265) compared to the moderator model including cognitive construct (corrected

Table 5
Moderator Analysis

Moderator	Basic cognitive functions		Higher cognitive functions		Cognitive decision-making skills	
	g	95% CI	*g*	95% CI	*g*	95% CI
Cognitive construct only	0.39	[0.21, 0.56]	0.44	[0.26, 0.62]	0.77	[0.60, 0.94]
Stimuli						
General	0.28	[0.03, 0.53]	0.34	[0.12, 0.56]	0.26	[−0.08, 0.60]
Specific	0.58	[0.31, 0.85]	0.64	[0.40, 0.89]	0.84	[0.67, 1.01]
Response						
General	0.36	[0.18, 0.54]	0.42	[0.25, 0.59]	0.70	[0.52, 0.88]
Specific	0.49	[−0.12, 1.09]	—	—	1.04	[0.66, 1.42]
Age group						
Late childhood	0.33	[0.06, 0.60]	0.43	[0.08, 0.79]	0.40	[−0.09, 0.89]
Adolescence	0.39	[0.14, 0.64]	0.47	[0.26, 0.68]	0.49	[0.25, 0.73]
Adulthood	0.38	[0.14, 0.62]	0.40	[0.08, 0.62]	0.90	[0.72, 1.09]
Design						
Cross-sectional	0.38	[0.19, 0.57]	0.43	[0.24, 0.62]	0.81	[0.62, 0.99]
Prospective	0.32	[−0.04, 0.68]	0.39	[0.16, 0.62]	0.44	[0.10, 0.78]

Note. Positive effect size indicates that higher skilled athletes outscore lower skilled athletes in cognitive tasks. *g* = Hedges' *g*.

AIC = 2,282), cognitive construct and stimuli (corrected AIC = 2,269), as well as cognitive construct and response (corrected AIC = 2,276).

Discussion

We synthesized published research that examined the relationship between cognition and performance in athletes. We explored whether the type of cognitive constructs and the sport-specificity of the tasks influence the relationship. Overall, we found that the type of cognitive construct and the sport-specificity of the stimuli used in the task were the most influential factors in differentiating higher- and lower skilled athletes. Meanwhile, the type of response used, the age group of the athletes, the kind of study design, and how the sporting performance was measured had small to nonexistent effects.

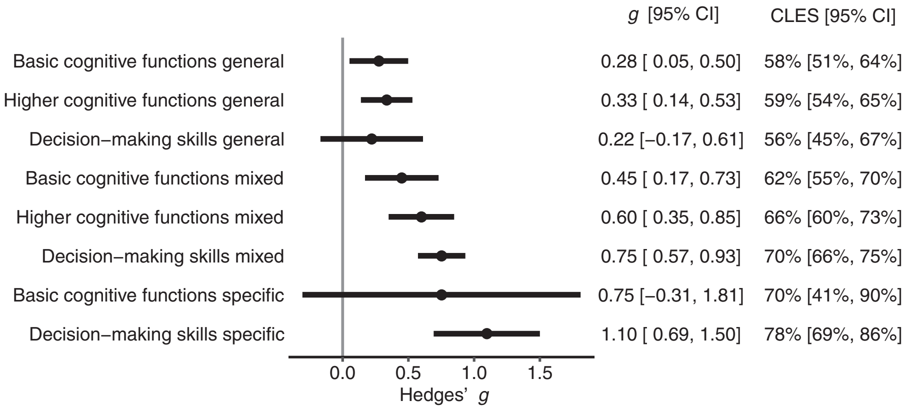
The meta-analysis results showed that decision-making tests were better at differentiating between higher- and lower skilled athletes than tests of basic and higher cognitive functions. This finding suggests that the more representative the cognitive test is of the skills used by athletes in competition, the more sensitive the measure is of expertise (i.e., cognitive skills such as decision-making differentiate better than general cognitive function between higher- and lower skilled athletes). Whether the advantage of specific measures for discriminating expertise levels reflects a higher level of sensitivity, a better fit of the functions and skills needed for the task, or a reflection of the combination of selection and training processes is unclear. Large-scale projects using both cross-sectional and longitudinal designs are needed. Our findings align with the conclusion from a previous review, which found a considerably larger effect size for decision-making compared to EF tests (Scharfen & Memmert, 2019). In this sense, from an applied perspective, general cognitive function is unlikely to offer any predictive utility for talent identification. This finding aligns with Beavan et al. (2020), who found that the developmental trajectories of EF in youth athletes follow the general population despite their expertise.

We found that tests using sport-specific stimuli were considerably more successful in differentiating higher- and lower skilled athletes than tests with non-sport-specific stimuli. As this meta-analysis aimed to compare different types of cognition, we classified all stimuli presenting sport movements, sequences, or situations as sport specific. In contrast, meta-analyses focusing more narrowly on decision-making or perceptual–cognitive skills in sport have used a finer-grained classification, dividing static, video, and in situ representations (Mann et al., 2007; Travassos et al., 2013). In line with our findings, these studies found that the more representative the research stimuli are of the performance environment, the better the tests discriminate between skill levels (Mann et al., 2007; Travassos et al., 2013). Conversely, meta-analyses on the connection between basic or higher cognitive functions and sport performance typically exclude tests using sport-specific stimuli (Scharfen & Memmert, 2019; Voss et al., 2010). Our findings highlight the importance of using a representative design (cf. Brunswik, 1956; Hammond & Stewart, 2001). It refers to the arrangement of conditions of an experiment so that they represent the behavioral setting to which the results are intended to apply (i.e., mimicking the task in the real world). Brunswik (1956) used the term "represent" in the same sense in which a sample of participants in an experiment might be said to "represent" individuals in some population that was not included in the experiment. The argument is that the generalization should hold for contexts as well as participants. Only by creating stimuli that capture the unique perceptual demands of each sports setting can researchers discover how the individual truly behaves in such circumstances. This point has been highlighted by many other researchers (Araújo et al., 2007; Barnett & Ceci, 2002; Hoffman & Deffenbacher, 1993; Risko et al., 2012; Williams et al., 2002).

Contrary to the type of stimuli employed, we found less evidence for sport-specific responses increasing the discriminatory ability of the tests. An earlier meta-analysis that included both stimuli and response type as moderators of connection between decision-making and sport expertise found that more sport-specific response types, as well as stimuli, increased the difference between more and less expert athletes (Travassos et al., 2013). The type of response showed no effect for any of the cognitive constructs analyzed, from basic and high cognitive functions to decision-making. This result also indicates that a snapshot "response" may be a narrow conceptualization of the role of goal-directed action in sport performance,

Figure 3

Post Hoc Subgroup Analysis for Combinations of Cognitive Constructs and Specificity of Tests



Note. Positive effect size indicates that higher skilled athletes outscore lower skilled athletes in cognitive tasks; CLES represents the chance that a randomly selected higher skilled athlete will outscore a randomly selected lower skilled athlete. CLES = common language effect size; *g* = Hedges' *g*.

as entailed by the stimulus-processing-response paradigm (contrast with Araújo et al., 2006; Correia et al., 2012). One can conclude that a cognitive task seems to be sensitive enough to capture skill group differences in sports if representative stimuli are employed, whereas a sport-specific response does not add explanatory power.

Looking at the other conceptually relevant moderators, we found no clear evidence of differences in effects across age groupings. The need for large-scale projects requires cross-sectional and longitudinal data in a design testing intraindividual and interindividual changes across the lifespan. Most published reports used an adult sample, and only 10 studies tested athletes in their late childhood. Furthermore, studies almost exclusively tested athletes from a single-age group. More studies on younger athletes, specifically using longitudinal designs across several age groups, are probably needed to gain more knowledge on the developmental effects of the relationship between sport performance and cognitive functions and/or on how to adopt measures of cognition within developmental samples.

Only 10 of the studies included used a prospective design, where the cognitive functions were measured before observing the skill of the athletes (e.g., performing cognitive tests before team selection was made). We found no clear evidence that the study design influenced the results. Most studies used cross-sectional designs, examining differences between predefined groups of higher- and lower skilled athletes. Although these studies can provide some evidence of the correlation between sport expertise and cognitive functions, they provide little value and guidance on how tests of cognitive functions can be used by practitioners to, for example, predict athletes' future sporting success (Ivarsson et al., 2020) or to improve performance (Renshaw et al., 2019). Given the interest in using cognitive tests to identify talented athletes in childhood and adolescence, it is noteworthy that we only identified three articles that prospectively assessed cognitive measures in youth athletes, which enables to predict their performance more than a year later (de Joode et al., 2021; Ishihara et al., 2019; Murr et al., 2021).

Over half of the studies had a risk of selection bias caused by the inadequate confirmation and consideration of confounding variables. It was evident that almost all these studies had either failed to report the amount of sport experience of the athletes or displayed differences in experience between higher- and lower skilled athletes, which were not statistically controlled. More specifically, as researchers have shown the positive impact of practice hours on, for example, inhibition and WM in open skill sports (e.g., Huijgen et al., 2015; Ishihara et al., 2019), it might be important to control for this potential effect when examining the relationship between cognitive functions and performance. One out of four articles showed a risk of selection bias caused by the inadequate selection of participants. In this case, the studies either did not control for differences in age or the proportion of male and female athletes included in the higher- and lower skilled groups. As these factors are related to cognitive functions and skills, failing to account for them may likely impact results (Grissom & Reyes, 2019; Huizinga et al., 2006; Jacobsen et al., 2017).

Although we found an indication of possible publication bias in the overall sample, we did not find any within each cognitive construct. This finding is possible due to the heterogeneity of the effect sizes, which could create a funnel plot asymmetry, not due to publication bias. Visual inspection of the funnel plots indicates an asymmetry in the relationship between effect size and precision, which can indicate publication bias. Although, the funnel plots ignore the clustered structure of multiple effect sizes within studies. In conclusion, the evidence of publication bias in the current review is inconclusive, and consequently, the interpretations should be considered with caution.

Limitations

An important limitation in this review is the low number of prospective studies, especially involving basic cognitive functions and decision-making. The scarcity of studies makes it impossible to conclude how cognitive functions can predict future performance. Another limitation is the lack of diversity in the samples studied. For example, a low number of female participants were employed. The lack of research on female athletes has been reported in other reviews (Williams et al., 2020). Furthermore, most studies were conducted using adult athletes, with only a few studies measuring athletes' cognitive functions/skills in late childhood or adolescence. Finally, most of the studies were conducted in Europe, North America, or Oceania. Samples from western nations have been shown to not generalize well in other psychological domains (Henrich et al., 2010). Given that the estimated effect sizes in our meta-analysis were based mainly on studies using western adult males, caution is warranted in generalizing the size of the effects to female, younger, and non-western populations.

Given the broad scope of this review, there are potentially important moderators that we did not consider in this review. For example, the type of sport practiced, how skill is defined, and the level of sporting expertise can affect the relationship between cognitive functions and sports performance (Scharfen & Memmert, 2019; Voss et al., 2010). Finally, the choice of how to analyze multiple dependent effect sizes from each study is not straightforward, and the choice might affect both the main results and publication bias analyses (Fernández-Castilla et al., 2021; Rodgers & Pustejovsky, 2021).

Practical Implications

The results showed that higher skilled athletes had better cognitive decision-making skills than lower skilled athletes, indicating that these skills might be an important component for athletic performance. Even if these types of skills cannot be used to predict future performance, we suggest that training programs targeting decision-making skills might be beneficial to improve performance. A systematic review focusing on decision-making training in volleyball showed that this type of training (e.g., perceptual training, video feedback) improved decision-making skills in volleyball players (Conejero Suárez et al., 2020). Similar positive effects have been shown for decision-making training programs in other team sports. More specifically, programs based on practical scenarios positively affect passing decisions and execution (Silva et al., 2020). The current knowledge in the field does not allow us to precisely recommend specific cognitive training regimes beyond the above decision-making programs (Harris et al., 2018; Walton et al., 2018).

In future studies, we suggest that researchers primarily adapt prospective designs to provide evidence of how cognitive functions influence future sporting performance. Moreover, we suggest that researchers report and control for differences in participant age, gender, and sport experience to ensure that extraneous factors do not influence the results. Finally, more studies must be undertaken using female athletes and younger participants to generalize findings to a broader group of athletes, as well as studies including measures at several different ages to allow for direct comparisons between different developmental stages. We need more mixed cross-sectional and longitudinal studies under stable situations (e.g., youth academics and sports schools), a theoretical test of different explanations of how sport-specificity, cognitive dimensions, and developmental stage interact with expertise (e.g., Musculus et al., 2019; Raab, 2012) and methodological developments in diagnostics that allow us to differentiate sensitivity, specificity for tests applied in talent selection and development.

Conclusions

Higher skilled athletes perform better on tests of cognitive function compared to lower skilled athletes. Tests of cognitive decision-making skills have a better ability to differentiate higher- and lower skilled athletes than tests of basic or higher cognitive functions. Using sport-specific tests seems important to be able to differentiate between higher- and lower skilled athletes. Still, due to the paucity of predictive studies, there was insufficient evidence to determine whether cognitive functions and skills can predict future sport performance. We found no evidence to support claims that tests of general cognitive functions, such as executive functioning, should be used by practitioners for talent identification or player selection.

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Received February 13, 2021
Revision received February 6, 2022
Accepted February 8, 2022 ■