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The role of domain-specific and domain-general cognitive functions and skills in sports performance: A meta-analysis

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Abstract

Cognition plays a key role in sports performance. In this meta-analytic review, we synthesize research that has examined the relationship between cognitive functions, skills, and sports performance. We identified literature by searching Cochrane library, PsychInfo, 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 9433 screened records, 136 reports were included, containing 142 studies, 1227 effect sizes, and 8860 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 size for sport-specific task-stimuli compared to general ones. We report that higher-skilled athletes perform better on tests of cognitive function compared to 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.

Keywords: cognitive functions; decision-making; expertise; sports level; sports performance.

Public Significance Statements

This meta-analysis indicates that testing cognitive functions or skills using sport-specific stimuli has the potential to differentiate between elite and non-elite athletes. There is,

however, no evidence for the usefulness of using general, non-sport-specific cognitive function tests to predict future sport performance.

The role of domain-specific and domain-general cognitive functions and skills in sports performance: A meta-analysis

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 paper, 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 sport 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, using mostly non-sport-specific tasks. In these studies, standardized or generic tasks do not contain stimuli or responses that are 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 non-athletes 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 non-athletes, 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 (Hujgen et al., 2015), no differences were found for working memory (Huijgen et al., 2015; Verburgh et al., 2014), meta-cognition (Huijgen et al., 2015), or orienting and executive attention (Verburgh et al., 2014). Other researchers have, however, suggested that there are consistent differences in working memory 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). However, 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, with this meta-analysis, we aim 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 in relation to 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 as being 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 that are relevant for 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 further be 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, examples of basic functions would be processing speed (Butzbach et al., 2019), whereas a prototypical example of higher cognitive functions would be executive functions (e.g., Miyake et al., 2000).

Executive functions (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 and coworkers (2000), who isolated three separate but highly correlated EFs, namely working memory (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, that takes place in working memory; and (c) behavioral inhibition, which stops automatic but inefficient responses (Friedman & Miyake, 2004). Lastly, 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 differently defined and categorized EFs (for a detailed overview, see Müller & Kerns, 2015). However, WM updating, inhibition, and shifting have been the most extensively investigated EFs, and, in the last ten years, they have been studied in relation to 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 in 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 specifically 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. However, this 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, whereas Gierczuk and colleagues (2018) measured Greco-Roman wrestlers processing speed with a sport-specific task. Therefore, we propose in our operational framework to clearly 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 to close a gap in the literature and to conceptually specify the domain-specific vs. 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 does produce observable differences in intentional, sport-specific behavior (e.g., placing a pass, scoring a goal) which in turn 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 clearly 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, 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 to be 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, to better understand the mechanisms underlying the cognition-performance relation, the study design has important conceptual consequences. 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 at the same point in time, an *association* at that specific point in time can be captured, however, 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 at a later date than the 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 executive functions to potentially help clubs identify and select athletes into systematic elite training programs that involve the selection and identification of ‘talented’ youth athletes (Mann et al., 2017; Kittelberger, 2018). 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 exists focusing on how a broad range of both cognitive functions and cognitive skills are related to sport performance, 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 non-athletes, 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. Furthermore, to test the effects of the age of the 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 (for an overview of moderators, see Table 1).

Method

The review was conducted following the PRISMA guidelines for systematic reviews (Page et al., 2021).

Literature search strategy

Literature searches were conducted using four electronic databases: Cochrane library; PsychInfo; Pubmed; and Web of Science Core Collection (Citation indexes: SCI-EXPANDED, SSCI, ESCI, CPCI-S, CPCI-SSH, A&HCI, BKCI-SSH, BKCI-S). The original searches were undertaken on 12 December 2019 and were updated on 19 January 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 used. For the full search strategy, see Appendix A. 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 for inclusion 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 season, selected or not into academy); (d) compared athletes competing within the same sport (e.g., soccer players in first division vs soccer players in 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 main dependent variables were not cognitive variables but visual ability (e.g., gaze-behavior), brain activity (e.g., 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 tasks; 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., working memory 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 being 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 response 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, or general otherwise. 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 with respect to 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’s (2014) stages of development. Finally, the design used was classified as prospective if the cognitive data were clearly collected before the collection of sport performance data, or cross-sectional if cognitive and sport performance data were collected at or around the same point in time.

The studies were classified independently by two authors (LM & EB), 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 and consensus was reached on 13 dimensions. For the 20 dimensions where they could not reach an agreement, it was 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 ($F_{(4,\ 1.9)} = 1.3$, $p = 0.481$; 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: 1) Selection of participants; 2) Confounding variables; 3) Measurement of exposure; 4) Blinding of outcome assessments; 5) Incomplete outcome data; and 6) 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* using the R package esc, 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 metafor and the robust variance was estimated using the clubSandwich package (Pustejovski, 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 pre-specified 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 (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.

To test for potential publication bias, we used an Egger's regression type test, 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 both with all effect sizes as well as separate for each cognitive construct.

We present the estimated effect sizes expressed as common language effect sizes, which represents 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 has been shown to provide 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 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 OSF repository available at http://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 12641 records through database searches in Cochrane library, PsychINFO, Pubmed, and Web of Science. After duplicate removal, the title and abstract of 9416 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 of these were included in the review. A total of 136 reports, containing 142 studies, and 1227 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 Appendix B. The included studies were published between 1995 and 2021. There was no significant effect of publication year on the effect size estimates ($t_{(29.9)} = 0.1$, $p = 0.911$). The studies included participants from a total of 39 sports. The most common sports were soccer (studies $k = 43$ [27%], participant $n = 3135$), 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* = 7845). The most common countries were United Kingdom (*k* = 28 [19%], *n* = 2136), Australia (*k* = 24 [16%], *n* = 1575), Germany (*k* = 20 [13%], *n* = 1204), 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 where it was reported that funding was received, none reported any funding from companies commercializing tests of cognitive functions. Six studies reported funding from sport 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 having used a commercial test system to measure basic and higher cognitive functions. No study specified the use of 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* = 4276), 39 (27%) contained measures of higher cognitive function (*n* = 3393), and 80 (56%) contained measures of cognitive decision-making skill (participants *n* = 4145), 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 & Barbosa 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., 2020; Vestberg et al., 2017; 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; Vestberg et al., 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%).

Study design

Of the included studies, 11 (8%) used a prospective design in at least part of the study (participants *n* = 1154). Of these, three used participants who were in late childhood with a total of 436 athletes (Ishihara et al. 2019; de Joode et al., 2021; 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 one 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 (Gabett 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 thereafter, 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 to their competitive ranking 18 months later (Sakamoto et al., 2018). Two studies (participants $n = 99$) had a follow up of over three years, testing how cognitive test scores relate to their chance of being selected into a youth national team over the next three years (Murr et al., 2021), and of becoming an elite athlete seven years later (de Joode et al., 2021).

Two prospective studies (participants $n = 528$) contained measures of basic cognitive functions, using reactive agility (Gabett 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; Vestberg et al., 2012; Sakamoto et al., 2018), 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 other domains, 0–4% of the studies showed a high risk of bias. We can see similar patterns of bias in studies measuring each of the cognitive constructs. 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 = 0.279; confounding variables: $F_{(1,\,117)} = 1.7$, p = 0.198; blinding of outcome assessments: $F_{(1,\,1.0)} = 6.3$, p = 0.236; incomplete outcome data: $F_{(2,\,10.4)} = 0.8$, p = 0.464; selective outcome reporting: $F_{(2,\,3.2)} = 1.6$, p = 0.296). No sensitivity analysis was run for the measurement of exposure as all studies had the same classification.

Publication bias

There was a significant relationship between effect size estimate and precision (0.80, SE = 0.34, $t_{(32.9)} = 2.4$, p = 0.025), indicating a possible publication bias. The separate tests for each cognitive construct did, however, not show evidence of publication bias in any of them (basic cognitive functions: 0.06, SE = 0.66, $t_{(16.6)} = 0.1$, p = 0.933; 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 = 0.144). 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, as well as for each combination of cognitive construct and each of the other moderators, are shown in Table 5.

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], $t_{(63.1)} = 4.4$, $p < 0.001$; higher cognitive functions g = 0.44, 95% CI [0.26, 0.62], $t_{(51.2)} = 4.9$, $p < 0.001$; cognitive decision-making skills g = 0.77, 95% CI [0.6, 0.94], $t_{(70.8)} = 9.2$, $p < 0.001$). 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 ($t_{(39.7)} = 3.1, p = 0.011$) and higher cognitive functions ($t_{(39.7)} = 2.7, p = 0.015$), whereas there was no significant difference between basic and higher cognitive functions ($t_{(18.6)} = 0.4, p = 0.397$). The chance that a randomly selected athlete from a higher-skilled group will outscore 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 so on tasks with specific compared to general stimuli (g specific stimuli − g general stimuli = 0.37, 95% CI [0.09, 0.65], $t_{(31.6)} = 2.7$ $p = 0.011$) 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 ($t_{(4.77)} = 4.3$, $p = 0.026$), but not for basic ($t_{(22.8)} = 1.5, p = 0.147$) or higher cognitive functions ($t_{(9.6)} = 1.8$, $p = 0.147$). 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],

$t_{(17.7)} = 1.8$ $p = 0.097$) 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 higher than for general stimuli within basic cognitive functions and cognitive decision-making skills, respectively (Table 5). However, the difference between specific and general responses was not significant for basic cognitive functions ($t_{(4.3)} = 0.6$, $p = 0.600$), nor for cognitive decision-making skills ($t_{(25.7)} = 1.7$, $p = 0.198$). There were no studies that 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 ($F_{(2,\,9.3)} = 2.5$, $p = 0.135$) when adjusting for the effect of cognitive construct. However, we found a general trend towards 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], $t_{(5.75)} = -1.6$ $p = 0.149$) 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 towards larger effect sizes the more complex the cognitive constructs and the more specific the tasks. 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 = 2265) compared to the moderator model including cognitive construct (corrected AIC = 2282), cognitive construct and stimuli (corrected AIC = 2269), as well as cognitive construct and response (corrected AIC = 2276).

Discussion

We synthesized published research that has 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 type of study design, and how the sporting performance was measured had small to non-existent effects.

The results of the meta-analysis showed that decision-making tests were better at differentiating between higher- and lower-skilled athletes compared to 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 executive function 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 executive function in youth athletes follows 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 compared to tests with non-sport-specific stimuli. As the aim of this meta-analysis was 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). These studies found, in line with our findings, 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, 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 intra-individual and inter-individual 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 working memory in open-skill sports (e.g., Huijgen et al., 2015; Ishihara et al., 2017), 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 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 be an indication of publication bias. The funnel plots, however, 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 draw conclusions about 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 small number of studies measuring the cognitive functions/skills of athletes 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 & Pustojevsky, 2021)

Practical Implications

The results showing that higher-skilled athletes had, in comparison to lower-skilled athletes, better cognitive decision-making skills indicates that these types of 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, Prado Serenini, Farnández-Echeverria, Collado-Mateo, & Arroyo, 2020). Similar positive effects have been shown for decision-making training programs in other team sports. More specifically, programs based on practical scenarios have positive effects on passing decisions and execution (Silva, Conte, & Clemente, 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 should report and control for differences in participant age, gender, and sport experience to ensure that the results are not influenced by extraneous factors. Finally, more studies must be undertaken using female athletes and younger participants to be able 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. However, 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 the purpose of talent identification or player selection.

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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, e.g., 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, e.g., 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	Skill 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, e.g., 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, e.g., 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 is collected at or around the same point in time.
Prospective	Cognitive data is clearly collected before the collection of performance level data.

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	1227	275	320	632
Number of participants	8860	4276	3393	4145
Number of females[b]	1442 (16%)	623 (15%)	696 (21%)	575 (14%)
Mean 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] 30 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] 27 studies did not specify gender of participants.

[c] 4 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.

Table 3

Commercial cognitive tests used in the literature.

Cognitive test	Studies
Cambridge Automated Neuropsychological Test Battery (CANTAB)	Hagyard et al., 2021 Vaughan & Edwards, 2020 Vaughan et al., 2021 Vaughan & Laborde, 2021 Vaughan et al., 2019
Cognifoot	Hicheur et al., 2017
CogState Sports	Vestberg et al., 2017 Vestberg et al., 2020
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., 2017 Vestberg et al., 2020
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%)

Table 5

Moderator analysis.

	Basic cognitive functions		Higher cognitive functions		Cognitive decision-making skills	
Moderator	*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. CI = Confidence interval, *g* = Hedges' *g*.

Figure 1

Flow of study reports into the research synthesis.

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.

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. CI = Confidence interval, CLES = Common language effect size, *g* = Hedges' *g*.

Appendix A

Search strategy.

Database	Full search term	Filters
Cochrane library	(cognitive OR executive function OR executive functions OR attention OR memory OR inhibitory control OR inhibition OR anticipation OR decision making OR reaction time) AND (sport OR sports OR athlete OR athletes OR player OR players) AND (expert OR experts OR elite OR talent OR talented OR professional)	- Trials
PsychInfo through ProQuest	AB,TI,SU((cognitive OR executive function OR executive functions OR attention OR memory OR inhibitory control OR inhibition OR anticipation OR decision making OR reaction time) AND (sport OR sports OR athlete OR athletes OR player OR players) AND (expert OR experts OR elite OR talent OR talented OR professional))	- Human
Pubmed	(“cognitive”[Title/Abstract] OR (“executive function”[MeSH Terms] OR (“executive”[Title/Abstract] AND “function”[Title/Abstract]) OR “executive function”[Title/Abstract]) OR (“executive function”[MeSH Terms] OR (“executive”[Title/Abstract] AND “function”[Title/Abstract]) OR “executive function”[Title/Abstract] OR (“executive”[Title/Abstract] AND “functions”[Title/Abstract]) OR “executive functions”[Title/Abstract]) OR (“attention”[MeSH Terms] OR “attention”[Title/Abstract]) OR (“memory”[MeSH Terms] OR “memory”[Title/Abstract]) OR (inhibitory[Title/Abstract] AND “control”[Title/Abstract]) OR (“inhibition (psychology)”[MeSH Terms] OR (“inhibition”[Title/Abstract] AND “(psychology)”[Title/Abstract]) OR “inhibition (psychology)”[Title/Abstract] OR “inhibition”[Title/Abstract]) OR “anticipation”[Title/Abstract] OR (“decision making”[MeSH Terms] OR (“decision”[Title/Abstract] AND “making”[Title/Abstract]) OR “decision making”[Title/Abstract]) OR (“reaction time”[MeSH Terms] OR (“reaction”[Title/Abstract] AND “time”[Title/Abstract]) OR “reaction time”[Title/Abstract])) AND ((“sports”[MeSH	- Humans

	Terms] OR “sports”[Title/Abstract] OR “sport”[Title/Abstract]) OR (“sports”[MeSH Terms] OR “sports”[Title/Abstract]) OR (“athletes”[MeSH Terms] OR “athletes”[Title/Abstract] OR “athlete”[Title/Abstract]) OR (“athletes”[MeSH Terms] OR “athletes”[Title/Abstract]) OR player[Title/Abstract] OR players[Title/Abstract]) AND (expert[Title/Abstract] OR experts[Title/Abstract] OR elite[Title/Abstract] OR (“aptitude”[MeSH Terms] OR “aptitude”[Title/Abstract] OR “talent”[Title/Abstract]) OR talented[Title/Abstract] OR professional[Title/Abstract])
Web of Science Core Collection (SCI-EXPANDED, SSCI, ESCI, CPCI-S, CPCI-SSH, A&HCI, BKCI-SSH, BKCI-S)	TS=((cognitive OR executive function OR executive functions OR attention OR memory OR inhibitory control OR inhibition OR anticipation OR decision making OR reaction time) AND (sport OR sports OR athlete OR athletes OR player OR players) AND (expert OR experts OR elite OR talent OR talented OR professional))

Appendix B

Study characteristics of studies containing tests of basic cognitive functions.

Author (year)	Study Design	Country	Sport	*n* (f %)	Age M ± SD (range)	Age group	Test type	Stimuli	Response	Performance type	Hedges' *g* [95% CI]
Bahia Loureiro & Barbosa de Freitas (2012)	Cross-sectional	Brazil	Badminton	24 (0%)	24 ± 5 (18–32)	Adulthood	Visual attention	General	General	Individual level	0.39 [0.05, 0.73]
Baláková et al. (2015)	Cross-sectional	Czech Republic	Soccer	91 (0%)	13 (13–13)	Late childhood	Vienna test system	General	General	Coach rating	-0.04 [-0.20, 0.11]
Boschker et al. (2002)	Cross-sectional	Netherlands	Climbing	9 (22%)	29 ± 6	Adulthood	Physical recall model	Specific	General	Individual ranking	0.85 [-2.14, 3.84]
Chung & Ng (2012)	Cross-sectional	China	Taekwondo	40 (38%)	20 ± 2 (18–24)	Adulthood	Audio attention Visual attention Image sport simulation	General Specific	General Specific	Individual level	-1.28 [-2.43, -0.14]
Didierjean & Marmèche (2005) Study 1	Cross-sectional	France	Basketball	42 (83%)	23 ± 3	Adulthood	Image recognition	General	General	Team level	-0.33 [-0.91, 0.25]
Didierjean & Marmèche (2005) Study 2	Cross-sectional	France	Basketball	28 (71%)	26 ± 7	Adulthood	Image recognition	General	General	Team level	0.21 [-0.28, 0.71]
Duncan et al. (2018)	Cross-sectional	United Kingdom	Futsal	23 (0%)	29 ± 5	Adulthood	Flanker test	General	General	Team level	0.17 [-0.65, 0.99]
Ehmann et al. (2022)	Cross-sectional	Germany	Soccer	292 0%	15 ± 3	Late childhood Adolescence Adulthood	Multiple object tracking	General	General	Team level	0.28 [0.04, 0.52]
Estevan & Falco (2013)	Cross-sectional	Spain	Taekwondo	33 (0%)	25 ± 6	Adulthood	Live sport simulation	General	Specific	Individual ranking	2.36 [1.82, 2.89]

Falco et al. (2013)	Cross-sectional	Spain	Taekwondo	49 (29%)	25 ± 6	Adulthood	Live sport simulation	General	Specific	Individual ranking	0.10 [-0.23, 0.42]
Gabbett & Benton (2009)	Cross-sectional	Australia	Rugby	69 --	24 ± 5	Adulthood	Reactive agility test	Specific	Specific	Team level	0.57 [0.21, 0.93]
Gabbett et al. (2011)	Prospective	Australia	Rugby	86 --	23 ± 4	Adulthood	Reactive agility test	Specific	Specific	Coach selection	0.02 [-0.30, 0.34]
García-González et al. (2012)	Cross-sectional	Spain	Tennis	12 --	16 ± 2	Adolescence	Verbal report	Specific	General	Individual ranking	1.04 [0.49, 1.59]
Gierczuk et al. (2018)	Cross-sectional	Poland	Wrestling	20 (0%)	21 ± 2	Adulthood	Visual attention	General	General	Individual ranking	1.28 [0.33, 2.22]
Gonzalez et al. (2017)	Cross-sectional	United Kingdom	Archery	20 (35%)	29 ± 12	Adulthood	Computer sport simulation	Specific	General	Individual level	0.00 [-0.62, 0.62]
Gorman et al. (2011)	Cross-sectional	Australia	Basketball	24 (0%)		Adulthood	Image recognition	General Specific	General	Individual level	0.31 [-0.12, 0.74]
Grigore et al. (2015)	Cross-sectional	Romania	Tennis	12 (0%)	(15–17)	Adulthood	Image recognition	General	General	Individual ranking	0.34 [-0.80, 1.48]
Gutierrez-Davila et al. (2013)	Cross-sectional	Spain	Fencing	30 (0%)	30 ± 11	Adulthood	Real-world sport simulation	General	Specific	Individual level	-0.18 [-0.69, 0.33]
Guzmán et al. (2008)	Cross-sectional	Spain	Orienteering	39 (0%)	28 ± 9 (16–55)	Adulthood	Questionaire	Specific General	General	Individual level	0.61 [0.25, 0.97]
Han et al. (2011)	Cross-sectional	South Korea	Baseball Soccer	70 (0%)	28 ± 4	Adulthood	Trail Making Test	General	General	Coach selection	-0.02 [-0.66, 0.61]
Heilmann (2021)	Cross-sectional	Germany	Climbing	19 (47%)	24 ± 4 (18–31)	Adulthood	Stroop test Corsi block-tapping test Trail Making Test Real-world recall	General Specific	General	Individual level	0.17 [-0.77, 1.12]
Hicheur et al. (2017)	Cross-sectional	Switzerland	Soccer	46 (4%)	13 ± 1 (11–16)	Late childhood	Cognifoot	General	Specific	Coach rating	0.81 [0.38, 1.23]
Holfelder et al. (2020)	Cross-sectional	Germany	Athletics Handball	86 (50%)	14 ± 1 (13–15)	Adolescence	0-back Flanker test	General	General	Individual level	0.17 [-0.04, 0.39]

							Trail Making Test				
Huijgen et al. (2015)	Cross-sectional	Netherlands	Soccer	88 (0%)	15 ± 1 (13–17)	Adolescence	D-KEFS: Trail making Test Stop-Signal Task	General	General	Individual level	0.20 [-0.10, 0.50]
Hüttermann et al. (2019)	Cross-sectional	Germany	Soccer	24 (0%)	24 ± 4 (19–32)	Adulthood	Visual attention: response accuracy	General	General	Team level	0.59 [-0.23, 1.41]
Kajtna et al. (2012)	Cross-sectional	Slovenia	Handball	46 (0%)	23 ± 4	Adulthood	Visual attention	General	General	Coach rating	-0.12 [-0.29, 0.05]
Kruger et al. (2019)	Cross-sectional	South Africa	Rugby	79 (0%)	25 ± 4 (19–37)	Adulthood	Memory Digit span recall test	General	General	Team level	-0.03 [-0.38, 0.33]
Laby et al. (2018)	Cross-sectional	USA	Baseball	450 (0%)	--	Adulthood	Visual attention	General	General	Performance	0.43 [0.35, 0.51]
Loveccio et al. (2021)	Cross-sectional	Italy	Soccer	68 0%	8 ± 0	Late childhood	Stroop test	General	General	Team level	0.76 [0.40, 1.12]
MacIntyre et al. (2002)	Cross-sectional	Various	Canoe slalom	31 (29%)	24 ± 5 (17–31)	Adulthood	Mental rotation task	General	General	Individual level	0.33 [-0.40, 1.05]
Millard et al. (2020)	Cross-sectional	South Africa	Rugby	80 (0%)	26 ± 5 (19–35)	Adulthood	Visual attention Memory: Response accuracy	General	General	Team level	1.09 [-0.01, 2.19]
Moreau et al. (2011)	Cross-sectional	France	Fencing Judo Wrestling	60 (50%)	23 (18–29)	Adulthood	Mental rotation task	General	General	Individual level	1.69 [1.10, 2.29]
Ottoboni et al. (2015)	Cross-sectional	Italy	Boxing	21 (0%)	23 ± 4 (17–32)	Adulthood	Image recognition	Specific	General	Individual level	-0.63 [-1.40, 0.14]
Patócs et al. (2016)	Cross-sectional	Hungary	Fencing	71 (45%)	27 ± 6 (18–40)	Adulthood	Vienna Test System: Determination test	General	General	Individual level	0.25 [-0.16, 0.66]
Przednowek et al. (2019)	Cross-sectional	Poland	Handball	40 (0%)	24 ± 4	Adulthood	Test2Drive system	General	General	Team level	0.08 [-0.23, 0.40]
Qiu et al. (2018)	Cross-sectional	China	Basketball	42 (0%)	21 ± 2 (18–26)	Adulthood	Multiple object tracking	General	General	Team level	0.75 [0.14, 1.37]

Ripoll et al. (1995)	Cross-sectional	France	Savate	12 --	26 (20–33)	Adulthood	Computer sport simulation	Specific	General	Individual level	0.12 [-0.51, 0.75]
Roca et al. (2013) Study 2	Cross-sectional	United Kingdom	Soccer	24 (0%)	24 ± 4	Adulthood	Verbal report	Specific	Specific	Individual level	0.95 [0.37, 1.54]
Sakamoto et al. (2018)	Prospective	Japan	Soccer	383 (0%)	10 ± 1 (8–11)	Late childhood	D-KEFS: Stroop test	General	General	Coach selection	0.18 [0.03, 0.32]
Schapschröer et al. (2016a)	Cross-sectional	Germany	Handball	21 (100%)	21 ± 4	Adulthood	Memory	Specific	General	Team level	0.17 [-0.15, 0.48]
Schapschröer et al. (2016b) Study 1	Cross-sectional	Germany	Handball	21 (100%)	24 ± 3	Adulthood	Memory	Specific	General	Team level	1.12 [0.46, 1.78]
Schapschröer et al. (2016b) Study 2	Cross-sectional	Germany	Handball	23 (100%)	22 ± 3	Adulthood	Memory	Specific	General	Team level	0.21 [-0.37, 0.80]
Shao et al. (2020)	Cross-sectional	China	Clay pigeon shooting	20 (25%)	24 ± 6	Adulthood	Flanker test	General	General	Individual level	-0.16 [-0.53, 0.20]
Sterkowicz-Przybycien et al. (2015)	Cross-sectional	Poland	Judo	23 (26%)	23 ± 3	Adulthood	d2 Test of attention	General	General	Individual level	0.32 [-0.01, 0.66]
Vänttinen et al. (2010)	Cross-sectional	Finland	Soccer	100 (0%)	< 16	Adolescence	Visual attention	General	General	Coach selection	-0.11 [-0.39, 0.17]
Vaughan et al. (2021)	Cross-sectional	United Kingdom	Various	341 (30%)	21 ± 2	Adulthood	CANTAB: Spatial Span test	General	General	Individual level	0.10 [-0.02, 0.22]
Vaughan & Laborde (2021)	Cross-sectional	United Kingdom	Basketball	359 (45%)	19 ± 1	Adulthood	CANTAB: Match to Sample Rapid Visual Information Task	General	General	Individual level	1.35 [0.98, 1.73]
Veale et al. (2010)	Cross-sectional	Australia	Australian Football	40 --	--	Adolescence	Reactive agility test	Specific	Specific	Coach selection	0.95 [0.48, 1.41]
Verburgh et al. (2014)	Cross-sectional	Netherlands	Soccer	126 (0%)	12 ± 2	Adolescence	Stop signal task Attention Network Test Visiospatial memory	General	General	Individual level	0.02 [-0.31, 0.36]

Verburgh et al. (2016a)	Cross-sectional	Netherlands	Soccer	117 (0%)	11 ± 1	Late childhood	Stop signal task Visiospatial memory Attention Network Test	General	General	Individual level	0.05 [-0.66, 0.76]
Vestberg et al. (2012)	Cross-sectional	Sweden	Soccer	57 (46%)	24 ± 4	Adulthood	D-KEFS: Stroop test Trail making Test	General	General	Team level	0.56 [0.18, 0.93]
Vestberg et al. (2017)	Cross-sectional	Sweden	Soccer	30 (0%)	15 (12–19)	Adolescence	CogStateSports D-KEFS: Stroop test Trail making Test	General	General	Performance	0.33 [0.12, 0.54]
Vestberg et al. (2020)	Cross-sectional	Sweden	Soccer	51 (63%)	25 ± 5 (17–35)	Adulthood	CogStateSports D-KEFS: Stroop test Trail making Test	General	General	Individual level Coach rating Performance	-0.02 [-0.50, 0.46]
Ward & Williams (2003)	Cross-sectional	United Kingdom	Soccer	137 (0%)	13 ± 0	Late childhood Adolescence	Visual attention Memory: Response accuracy	Specific	General	Team level	0.36 [-0.44, 1.15]
Whitaker et al. (2020) Study 2		USA	Climbing	20 (40%)	28 ± 7 (20–45)	Adulthood	Corsi block-tapping test Visual attention	General Specific	General	Individual ranking	0.54 [0.14, 0.95]
Williams & Davids (1998)	Cross-sectional	United Kingdom	Soccer	24 (0%)	23 ± 4	Adulthood	Choice reaction test	General	General	Individual level	-0.67 [-1.79, 0.46]
Williams & Davids (1995)	Cross-sectional	United Kingdom	Soccer	24 --	24 ± 4	Adulthood	Choice reaction test	General	General	Individual level	0.02 [-0.62, 0.65]

Note. Positive effect size indicates that higher-skilled athletes outscore lower-skilled athletes in cognitive tasks. CI = Confidence interval, f % = Percent of participants that were female, M = mean, SD = standard deviation.

Appendix C

Study characteristics of studies containing tests of higher cognitive functions.

Author (year)	Study Design	Country	Sport	*n* (f %)	Age M ± SD (range)	Age group	Test type	Stimuli	Response	Performance type	Hedges' *g* [95% CI]
Alarcón et al. (2017)	Cross-sectional	Spain	Basketball	34 (0%)	23 ± 3	Adulthood	D-KEFS: Design fluency test Stroop test	General	General	Team level	0.46 [-0.25, 1.16]
Baláková et al. (2015)	Cross-sectional	Czech Republic	Soccer	91 (0%)	13 (13–13)	Late childhood	Vienna test system	General	General	Coach rating	-0.44 [-0.86, -0.02]
Cona et al. (2015)	Cross-sectional	Italy	Ultra Marathon	30 (0%)	43 ± 9	Adulthood	Go/Nogo test N-back: 2-back	General	General	Performance	0.21 [-0.22, 0.64]
Duncan et al. (2018)	Cross-sectional	United Kingdom	Futsal	23 (0%)	29 ± 5	Adulthood	Flanker test	General	General	Team level	0.35 [-0.47, 1.18]
Elferink-Gemser et al. (2018)	Cross-sectional	Netherlands	Table tennis	60 (60%)	16 ± 4	Adolescence	D-KEFS: Design fluency test Stroop test Trail making test	General	General	Individual ranking	0.37 [0.00, 0.73]
Farrow et al. (2010)	Cross-sectional	Australia	Rugby	35 --	26 ± 4	Adulthood	Video temporal occlusion	Specific	General	Team level	1.18 [0.67, 1.70]
Gabbett et al. (2011)	Prospective	Australia	Rugby	86 --	23 ± 4	Adulthood	Video temporal occlusion	Specific	General	Coach selection	0.07 [-0.32, 0.45]
García-González et al. (2012)	Cross-sectional	Spain	Tennis	12 --	16 ± 2	Adolescence	Verbal report	Specific	General	Individual ranking	0.99 [0.56, 1.41]
Hagyard et al. (2021) Study 1	Cross-sectional	United Kingdom	Various	69 (54%)	21 ± 6	Adulthood	CANTAB: Stop-Signal Task	General	General	Individual level	0.59 [0.42, 0.75]
Hagyard et al. (2021) Study 2	Cross-sectional Prospective	United Kingdom	Basketball Rugby Soccer	91 (32%)	20 ± 1	Adulthood	CANTAB: Stop-Signal Task	General	General	Individual level Coach rating	0.67 [0.52, 0.81]

Han et al. (2011)	Cross-sectional	South Korea	Baseball Soccer	70 (0%)	28 ± 4	Adulthood	Trail Making Test Wisconsin Card Sorting Test	General	General	Coach selection	0.31 [-0.06, 0.69]
Heilmann (2021)	Cross-sectional	Germany	Climbing	19 (47%)	24 ± 4 (18–31)	Adulthood	Stroop test Trail Making Test Wisconsin Card Sorting Test	General Specific	General	Individual level	0.31 [-0.06, 0.69]
Holfelder et al. (2020)	Cross-sectional	Germany	Athletics Handball	86 (50%)	14 ± 1 (13–15)	Adolescence	N-back: 1- and 2-back Flanker test Trail Making Test	General	General	Individual level	0.18 [0.01, 0.36]
Huijgen et al. (2015)	Cross-sectional	Netherlands	Soccer	88 (0%)	15 ± 1 (13–17)	Adolescence	D-KEFS: Backward Visual Memory Span Design fluency test Trail making Test Stop-Signal Task	General	General	Individual level	0.49 [0.28, 0.71]
Ishihara et al. (2019)	Cross-sectiona Prospective	Japan	Tennis	40 (50%)	13 ± 2 (9–15)	Late childhood	D-KEFS: Design fluency test	General	General	Individual competitive ranking	0.69 [0.23, 1.14]
Kajtna et al. (2012)	Cross-sectional	Slovenia	Handball	46 (0%)	23 ± 4	Adulthood	Test of Series	General	General	Coach rating	0.02 [-0.40, 0.43]
Kida et al. (2005)	Cross-sectional	Japan	Baseball Tennis	61 (0%)	22 ± 2	Adulthood	Go/Nogo test	General	General	Coach rating Team level	0.35 [0.10, 0.61]
Kruger et al. (2019)	Cross-sectional	South Africa	Rugby	79 (0%)	25 ± 4 (19–37)	Adulthood	Stroop test	General	General	Team level	-0.02 [-0.50, 0.46]
Loveccio et al. (2021)	Cross-sectional	Italy	Soccer	68 0%	8 ± 0	Late childhood	Stroop test	General	General	Team level	0.93 [0.57, 1.29]
Lu et al. (2021)	Cross-sectional	China	Archery Shooting	111 (41%)	22 ± 5 (14–40)	Adulthood	Flanker test	General	General	Individual level	0.52 [0.25, 0.79]
Lundgren et al. (2016)	Cross-sectional Prospective	Sweden	Ice hockey	48 (0%)	24 ± 5	Adulthood	D-KEFS: Design fluency test Trail Making Test	General	General	Team level Performance Coach rating	0.26 [-0.04, 0.56]

North et al. (2017)	Cross-sectional	United Kingdom	Soccer	23	21 ± 2	Adulthood	Animated temporal occlusion	Specific	General	Individual level	1.47 [0.37, 2.57]
O'Connor et al. (2016)	Prospective	Australia	Soccer	127 (0%)	15 ± 0	Adolescence	Video temporal occlusion	Specific	General	Coach selection	0.13 [-0.22, 0.49]
Perciavalle et al. (2014)	Cross-sectional	Italy	Swimming	21 (0%)	20 ± 2 (16–24)	Adulthood	Tower of London test	General	General	Performance	0.89 [-0.01, 1.79]
Przednowek et al. (2019)	Cross-sectional	Poland	Handball	40 (0%)	24 ± 4	Adulthood	Test2Drive system	General	General	Team level	0.05 [-0.18, 0.27]
Roca et al. (2013) Study 2	Cross-sectional	United Kingdom	Soccer	24 (0%)	24 ± 4	Adulthood	Verbal report	Specific	General	Individual level	1.61 [0.82, 2.39]
Sakamoto et al. (2018)	Prospective	Japan	Soccer	383 (0%)	10 ± 1 (8–11)	Late childhood	D-KEFS: Stroop test Design fluency test	General	General	Coach selection	0.24 [0.09, 0.39]
Shao et al. (2020)	Cross-sectional	China	Clay pigeon shooting	20 (25%)	24 ± 6	Adulthood	Flanker test	General	General	Individual level	0.50 [0.13, 0.87]
van de Water et al. (2017)	Cross-sectional	Netherlands	Badminton	24 (0%)	25 ± 7	Adulthood	Stop signal task	General	General	Individual level Individual competitive ranking	0.40 [0.02, 0.79]
van Maarseveen et al. (2018)	Cross-sectional	Netherlands	Soccer	22 (100%)	16 ± 1	Adolescence	Video temporal occlusion	Specific	General	Performance	-0.33 [-0.93, 0.26]
Vaughan & Edwards (2020)	Cross-sectional	United Kingdom	Various	278 (43%)	22 ± 2	Adulthood	CANTAB: Intra-Extra Dimensional Set Shift Test Stop-Signal task Spatial Working-Memory test	General	General	Individual level	0.30 [0.13, 0.47]
Vaughan et al. (2021)	Cross-sectional	United Kingdom	Various	341 (30%)	21 ± 2	Adulthood	CANTAB: Spatial Working-Memory test	General	General	Individual level	0.65 [0.37, 0.92]
Vaughan & Laborde (2021)	Cross-sectional	United Kingdom	Basketball	359 (45%)	19 ± 1	Adulthood	CANTAB: Visual Search Task Spatial Span test	General	General	Individual level	0.46 [0.18, 0.74]

							Spatial Working-Memory test				
Verburgh et al. (2014)	Cross-sectional	Netherlands	Soccer	126 (0%)	12 ± 2	Adolescence	Stop signal task Flanker test Visiospatial memory	General	General	Individual level	0.44 [0.07, 0.81]
Verburgh et al. (2016a)	Cross-sectional	Netherlands	Soccer	117 (0%)	11 ± 1	Late childhood	Stop signal task Visiospatial memory WISC III Flanker test	General	General	Individual level	0.29 [-0.18, 0.75]
Verburgh et al. (2016b)	Cross-sectional	Netherlands	Soccer	44 (18%)	12 ± 1	Adolescence	Serial Reaction Time Task	General	General	Team level	0.18 [-0.11, 0.47]
Vestberg et al. (2012)	Cross-sectional Prospective	Sweden	Soccer	57 (46%)	24 ± 4	Adulthood	D-KEFS: Design fluency test Stroop test Trail making Test	General	General	Team level Performance	0.79 [0.50, 1.08]
Vestberg et al. (2017)	Cross-sectional	Sweden	Soccer	30 (0%)	15 (12–19)	Adolescence	CogStateSports D-KEFS: Design fluency test Stroop test Trail making Test	General	General	Performance	0.44 [0.27, 0.62]
Vestberg et al. (2020)	Cross-sectional	Sweden	Soccer	51 (63%)	25 ± 5 (17–35)	Adulthood	CogStateSports D-KEFS: Design fluency test Stroop test Trail making Test	General	General	Individual level Coach rating Performance	0.39 [0.25, 0.52]

Note. Positive effect size indicates that higher-skilled athletes outscore lower-skilled athletes in cognitive tasks. CI = Confidence interval, f % = Percent of participants that were female, M = mean, SD = standard deviation.

Appendix D

Study characteristics of studies containing tests of cognitive decision-making skills.

Author (year)	Study Design	Country	Sport	*n* (f %)	Age M ± SD (range)	Age group	Test type	Stimuli	Response	Performance type	Hedges' *g* [95% CI]
Araújo et al. (2005)	Cross-sectional	Portugal	Sailing	35 (26%)	23 ± 5 (17–40)	Adulthood	Computer sport simulation	Specific	General	Individual ranking	0.19 [-0.05, 0.42]
Bennet et al. (2020)	Cross-sectional	Australia	Soccer	165 (0%)	14 ± 1	Late childhood Adolescence	Video temporal occlusion	Specific	General	Team level	-0.15 [-0.46, 0.17]
Bruce et al. (2012)	Cross-sectional	Australia	Netball	38 (100%)	26 ± 5	Adulthood	Video temporal occlusion	Specific	General	Individual level	0.88 [0.22, 1.55]
Campbell & Moran (2014)	Cross-sectional	Ireland	Golf	31 --	24 ± 4 (16–28)	Adulthood	Real-world sport simulation	Specific	General	Individual level	0.48 [-0.37, 1.33]
Cañal-Bruland et al. (2011)	Cross-sectional	Netherlands	Tennis	40 --	26 ± 16	Adulthood	Animated temporal occlusion	Specific	General	Individual level	1.26 [0.58, 1.94]
Causer & Williams (2015)	Cross-sectional	United Kingdom	Soccer	24 --	24 ± 6	Adulthood	Video temporal occlusion	Specific	General	Individual level	4.25 [2.77, 5.73]
Chen et al. (2020)	Cross-sectional	Taiwan	Baseball	34 --	22 ± 2	Adulthood	Video temporal occlusion	Specific	General	Individual level	0.69 [0.34, 1.04]
Correia et al. (2012)	Cross-sectional	United Kingdom	Rugby	37 --	24 ± 5	Adulthood	Virtual reality sport simulation	Specific	Specific	Individual level	0.48 [0.00, 0.95]
de Joode et al. (2021)	Cross-sectional Prospective	Netherlands	Soccer	13 (0%)	12 ± 1	Late childhood	Video temporal occlusion	Specific	Specific	Coach rating Individual level	0.56 [-0.04, 1.16]
De Waelle et al. (2022)	Cross-sectional	Belgium	Badminton	41 --	24 ± 9 (13–57)	Adulthood	Video temporal occlusion	Specific	Specific	Individual level	0.07 [-0.15, 0.29]
del Campo & Caja (2018)	Cross-sectional	Spain	Soccer	16 (0%)	22 ± 2 (20–26)	Adulthood	Video temporal occlusion	Specific	Specific	Team level	0.50 [-0.32, 1.32]

Del Percio et al. (2007)	Cross-sectional	Italy	Karate	31 (29%)	22 ± 4 (18–31)	Adulthood	Image sport simulation	General Specific	General	Individual level	0.36 [-0.42, 1.14]
Farahani, Soltani, & Rezlescu (2020)	Cross-sectional	United Kingdom	Soccer	73 (0%)	19 ± 2 (15–23)	Adulthood	Video temporal occlusion	Specific	General	Coach rating	1.61 [1.28, 1.94]
Farahani, Soltani, Rezlescu, & Walsh (2020)	Cross-sectional	United Kingdom	Soccer	118 (0%)	18 ± 2 (15–23)	Adulthood	Video temporal occlusion	Specific	General	Coach rating	1.20 [1.03, 1.36]
Farrow et al. (2010)	Cross-sectional	Australia	Rugby	35 --	26 ± 4	Adulthood	Video temporal occlusion	Specific	General	Team level	1.48 [1.04, 1.91]
Gabbett & Abernethy (2013)	Cross-sectional	Australia	Rugby	88 --	20 ± 4	Adolescence Adulthood	Video temporal occlusion	Specific	Specific	Team level	1.12 [0.88, 1.35]
Gabbett et al. (2011)	Prospective	Australia	Rugby	86 --	23 ± 4	Adulthood	Video temporal occlusion	Specific	General	Coach selection	0.07 [-0.20, 0.33]
Gray et al. (2007)	Cross-sectional	USA	Baseball	16 (0%)	(19–26)	Adulthood	Video temporal occlusion	Specific	General	Individual level	1.63 [0.27, 2.98]
Hagemann (2009)	Cross-sectional	Germany	Tennis	72 (0%)	25 ± 4	Adulthood	Video temporal occlusion	Specific	General	Individual level	0.88 [0.48, 1.29]
Hagemann et al. (2010)	Cross-sectional	Germany	Fencing	30 30%	22 ± 6	Adulthood	Video spatial occlusion	Specific	General	Individual level	0.20 [-0.16, 0.56]
Heilmann (2021)	Cross-sectional	Germany	Climbing	19 (47%9	24 ± 4 (18–31)	Adulthood	Real-world decision-making	Specific	General	Individual level	1.83 [0.19, 3.47]
Holfelder et al. (2020)	Cross-sectional	Germany	Athletics Handball	86 (50%)	14 ± 1 (13–15)	Adolescence	Game of Dice	General	General	Individual level	-0.22 [-0.75, 0.31]
Huesmann et al. (2021)	Cross-sectional	Germany	Handball	45 0%	29 ± 7	Adulthood	Video temporal occlusion	Specific	Specific General	Team level	0.44 [-0.41, 1.29]
Hüttermann et al. (2019)	Cross-sectional	Germany	Soccer	24 (0%)	24 ± 4 (19–32)	Adulthood	Visual attention	Specific	General	Team level	1.27 [0.38, 2.15]
Joseph et al. (2021)	Prospective	Australia	Basketball	59 49%	16 ± 1	Adolescence	Video temporal occlusion	Specific	General	Coach selection	0.05 [-0.46, 0.56]
Keller et al. (2018)	Cross-sectional	Australia	Soccer	62 (0%)	17 ± 1 (16–18)	Adolescence	Video temporal occlusion	Specific	General	Individual level	1.44 [0.71, 2.17]

Laborde & Raab (2013)	Cross-sectional	Germany	Handball	60 --	25 ± 4 (17–33)	Adulthood	Video temporal occlusion	Specific	General	Team level	0.57 [-0.08, 1.23]
Liu et al. (2017)	Cross-sectional	USA	Tennis	74 (41%)	21 ± 6	Adulthood	Video temporal occlusion	Specific	General	Individual level	0.02 [-0.28, 0.32]
Lorains et al. (2013)	Cross-sectional	Australia	Australian Football	66 (0%)	22 ± 3 (18–30)	Adulthood	Video temporal occlusion	Specific	General	Team level	1.36 [0.47, 2.26]
Lyons et al. (2008)	Cross-sectional	Ireland	Hurling	20 --	25 ± 7	Adulthood	Bassin Anticipation	General	Specific	Team level	0.21 [-0.08, 0.51]
Magnaguagno & Hossner (2020)	Cross-sectional	Germany Switzerland	Handball	24 (0%)	26 ± 4	Adulthood	Virtual reality sport simulation	Specific	Specific	Individual level	1.77 [0.82, 2.72]
McRobert et al. (2011)	Cross-sectional	United Kingdom	Cricket	20	24 ± 5	Adulthood	Video temporal occlusion	Specific	General	Individual level	1.71 [0.67, 2.74]
McRobert et al. (2009)	Cross-sectional	United Kingdom	Cricket	20 (0%)	25 ± 6	Adulthood	Video sport simulation	Specific	Specific	Individual level	2.41 [1.23, 3.58]
Moore & Müller (2014)	Cross-sectional	USA	Baseball	12 (0%)	24 ± 3 (18–28)	Adulthood	Video temporal occlusion	Specific General	General	Team level	0.32 [-0.13, 0.77]
Moran et al. (2016)	Cross-sectional	Ireland	Equestrian	10 (40%)	(18–60)	Adulthood	Pupil dilation	Specific	General	Individual level	1.37 [0.73, 2.01]
Morris-Binelli et al. (2018)	Prospective	USA	Baseball	105 --	23 (19–33)	Adulthood	Video temporal occlusion	Specific	General	Performance	0.12 [0.07, 0.17]
Müller et al. (2010)	Cross-sectional	Australia	Cricket	26 (0%)	21 ± 4 (15–29)	Adulthood	Video spatial occlusion	Specific	General	Team level	0.79 [0.48, 1.10]
Müller et al. (2015)	Cross-sectional	Australia	Rugby	34 (0%)	24 ± 4 (18–33)	Adulthood	Video temporal occlusion	Specific General	General	Team level	0.18 [-0.09, 0.45]
Müller et al. (2017)	Cross-sectional	USA	Baseball	125 --	23 (19–33)	Adulthood	Video temporal occlusion	Specific	General	Individual level	0.09 [-0.18, 0.36]
Müller & Fadde (2016)	Cross-sectional	USA	Baseball	34 (0%)	21 (17–24)	Adulthood	Video temporal occlusion	Specific	General	Performance	0.07 [-0.04, 0.19]
Murphy et al. (2016) Study 1	Cross-sectional	United Kingdom	Tennis	36 (0%)	24 ± 5	Adulthood	Video temporal occlusion	Specific	Specific	Individual level	1.28 [0.52, 2.05]

							Animated temporal occlusion				
Murphy et al. (2016) Study 2	Cross-sectional	United Kingdom	Tennis	20 (0%)	26 ± 5	Adulthood	Animated temporal occlusion	Specific	Specific	Individual level	1.78 [0.73, 2.83]
Murr et al. (2021)	Cross-sectional Prospective	Germany	Soccer	86 (0%)	17 ± 1 (15–19)	Adolescence	Video temporal occlusion	Specific	Specific	Individual level	0.28 [0.01, 0.55]
Musculus (2018)	Cross-sectional	Germany	Soccer	169 (0%)	11 ± 2	Late childhood	Video temporal occlusion	Specific	General	Team level	-0.01 [-0.25, 0.23]
Musculus et al. (2021)	Cross-sectional	Germany	Soccer	80 (0%)	26 ± 1	Adulthood	Video temporal occlusion	Specific	General	Team level	-0.01 [-0.12, 0.10]
North et al. (2016)	Cross-sectional	United Kingdom	Soccer	24 --	21 ± 3	Adulthood	Video temporal occlusion Animated temporal occlusion	Specific	General	Individual level	1.71 [0.24, 3.17]
North et al. (2011)	Cross-sectional	United Kingdom	Soccer	19 (0%)	25 ± 3	Adulthood	Video temporal occlusion Memory	Specific	General	Individual level	0.64 [-0.34, 1.62]
O'Connor et al. (2016)	Prospective	Australia	Soccer	127 (0%)	15 ± 0	Adolescence	Video temporal occlusion	Specific	General	Coach selection	0.57 [0.11, 1.03]
Paull & Glencross (1997)	Cross-sectional	Australia	Baseball	30 (0%)	26	Adulthood	Video temporal occlusion	Specific	General	Individual level	1.12 [0.58, 1.67]
Piggott et al. (2019)	Cross-sectional	Australia	Australian Football	40 (0%)	24 (19–30)	Adulthood	Real-world sport simulation	Specific	Specific	Team level	0.26 [-0.37, 0.89]
Práxedes et al. (2018)	Cross-sectional	Spain	Soccer	19 --	11 ± 1	Late childhood	Real-world sport simulation	Specific	Specific	Team level	1.70 [0.91, 2.48]
Raab & Johnson (2007)	Cross-sectional	Germany	Handball	69 (42%)	16 ± 2	Adolescence	Video temporal occlusion	Specific	General	Team level	0.17 [0.08, 0.25]

Raab & Laborde (2011)	Cross-sectional	Germany	Handball	54 (50%)	15 ± 2	Adolescence	Video temporal occlusion	Specific	General	Team level	0.24 [-0.02, 0.50]
Ripoll et al. (1995)	Cross-sectional	France	Savate	12 --	26 (20–33)	Adulthood	Computer sport simulation	Specific	General	Individual level	0.27 [-0.35, 0.89]
Robertson et al. (2021)	Cross-sectional	Belgium	Badminton	41 22%	24 ± 9 (13–57)	Adulthood	Video temporal occlusion	Specific	Specific	Individual level	0.05 [-0.11, 0.21]
Roca et al. (2013) Study 1	Cross-sectional	United Kingdom	Soccer	24 (0%)	24 ± 3	Adulthood	Video temporal occlusion	Specific	Specific	Individual level	4.11 [3.09, 5.13]
Roca et al. (2013) Study 2	Cross-sectional	United Kingdom	Soccer	24(0%)	24 ± 4	Adulthood	Video temporal occlusion	Specific	Specific	Individual level	4.00 [3.00, 5.01]
Rosalie & Müller (2013)	Cross-sectional	Australia	Karate	14 --	25 ± 8 (18–46)	Adulthood	Real-world temporal occlusion	Specific	Specific	Individual level	2.00 [1.34, 2.67]
Rösch et al. (2021)	Cross-sectional	Germany	Basketball	13 (0%)	16 ± 0	Adolescence	Video temporal occlusion	Specific	General	Performance	1.85 [0.91, 2.79]
Rowe & McKenna (2001)	Cross-sectional	United Kingdom	Tennis	22 --	21 ± 3	Adulthood	Video temporal occlusion	Specific	General	Individual level	0.49 [-0.18, 1.16]
Schorer et al. (2013)	Cross-sectional	Germany	Soccer	24 (100%)	21 ± 4	Adulthood	Video spatial occlusion Video temporal occlusion	Specific	General	Team level	0.65 [0.31, 0.99]
Serpell et al. (2010)	Cross-sectional	Australia	Rugby	30 --	> 18	Adulthood	Reactive agility test	Specific	Specific	Team level	1.81 [0.95, 2.66]
Shangguan & Che (2018)	Cross-sectional	China	Tennis	30 (33%)	19	Adulthood	Image recognition	Specific	General	Individual level	2.38 [1.39, 3.37]
Spittle et al. (2010)	Cross-sectional	Australia	Basketball	38 (53%)	21 ± 2 (18–29)	Adulthood	Video temporal occlusion	Specific	General	Individual level	-0.03 [-0.73, 0.66]
Timmerman et al. (2021)	Cross-sectional	Australia	Field hockey	205 (46%)	14 ± 1	Late childhood	Video temporal occlusion	Specific	Specific	Coach selection	0.60 [0.25, 0.96]
Vaeyens et al. (2007)	Cross-sectional	Belgium	Soccer	65 (0%)	15 ± 1 (13–16)	Adolescence	Video temporal occlusion	Specific	Specific	Individual level	0.45 [0.26, 0.65]

van Maarseveen et al. (2018)	Cross-sectional	Netherlands	Soccer	22 (100%)	16 ± 1	Adolescence	Video temporal occlusion	Specific	General	Performance	-0.06 [-0.72, 0.59]
Vansteenkiste et al. (2014)	Cross-sectional	Belgium	Volleyball	20 (100%)	21 ± 2	Adulthood	Video temporal occlusion	Specific	Specific	Team level	0.70 [-0.59, 1.98]
Vater et al. (2016)	Cross-sectional	United Kingdom	Soccer	22 (0%)	21 ± 4	Adulthood	Video temporal occlusion	Specific	General	Individual level	1.32 [0.99, 1.65]
Vaughan et al. (2019)	Cross-sectional	United Kingdom	Various	188 (43%)	22 ± 2 (18–26)	Adulthood	CANTAB: Gambling Task	General	General	Individual level	0.55 [0.12, 0.99]
Vila-Maldonado et al. (2014)	Cross-sectional	Spain	Volleyball	40 (100%)	24 ± 5	Adulthood	Video temporal occlusion	Specific	General	Individual level	0.57 [-0.16, 1.30]
Ward & Williams (2003)	Cross-sectional	United Kingdom	Soccer	137 (0%)	13 ± 0	Late childhood Adolescence	Video temporal occlusion	Specific	General	Team level	0.14 [-0.27, 0.55]
Weissensteiner et al. (2008)	Cross-sectional	Australia	Cricket	102 (0%)	18 ± 5 (10–38)	Adolescence	Video temporal occlusion	Specific	General	Individual level	0.43 [0.15, 0.71]
Whitaker et al. (2020) Study 1	Cross-sectional	USA	Climbing	34 (59%)	25 ± 6 (18–34)	Adulthood	Live sport judgement task	Specific	General	Individual ranking	0.62 [-0.62, 1.87]
Williams & Davids (1998)	Cross-sectional	United Kingdom	Soccer	24 --	24 ± 4	Adulthood	Video spatial occlusion	Specific	General	Individual level	0.60 [0.37, 0.83]
Williams & Davids (1995)	Cross-sectional	United Kingdom	Soccer	24 --	25 ± 4	Adulthood	Video temporal occlusion	Specific	General	Individual level	0.76 [-0.55, 2.08]
Williams et al. (2002)	Cross-sectional	United Kingdom	Tennis	16 (0%)	25 ± 6	Adulthood	Video temporal occlusion	Specific	Specific	Individual level	1.03 [-0.14, 2.21]
Williams et al. (2012)	Cross-sectional	United Kingdom	Soccer	60 (0%)	18 ± 2	Adulthood	Video temporal occlusion Verbal recall	Specific	General	Individual level	1.79 [0.53, 3.04]
Woods, Raynor, Bruce, & McDonald (2016)	Cross-sectional	Australia	Australian Football	50 --	18 ± 1	Adolescence	Video temporal occlusion	Specific	General	Coach selection	2.71 [1.94, 3.48]
Woods, Raynor, Bruce, McDonald, & Robertson (2016)	Cross-sectional	Australia	Australian Football	84 --	18 ± 1	Adolescence	Video temporal occlusion	Specific	General	Coach selection	1.29 [0.82, 1.76]

Note. Positive effect size indicates that higher-skilled athletes outscore lower-skilled athletes in cognitive tasks. CI = Confidence interval, f % = Percent of participants that were female, M = mean, SD = standard deviation.

Appendix E

Forest plot of effect sizes basic cognitive functions.

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

Appendix F

Forest plot of effect sizes higher cognitive functions.

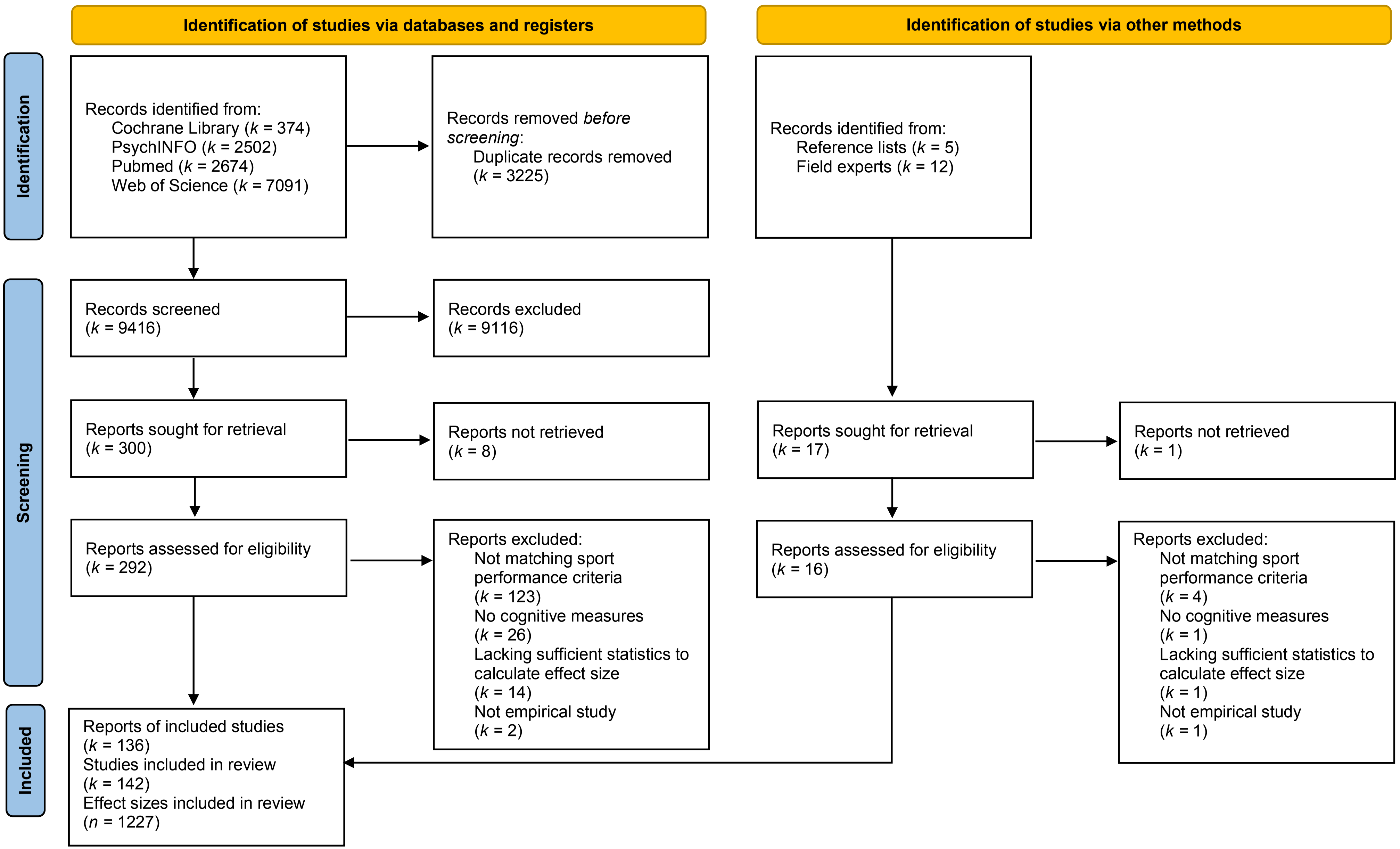
Note. Positive effect size indicates that higher-skilled athletes outscore lower-skilled athletes in cognitive tasks. CI = Confidence interval, *g* = Hedges' *g*.

Appendix G

Forest plot of effect sizes cognitive decision-making skills.

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

Figure 1. Flow of study reports into the research synthesis.



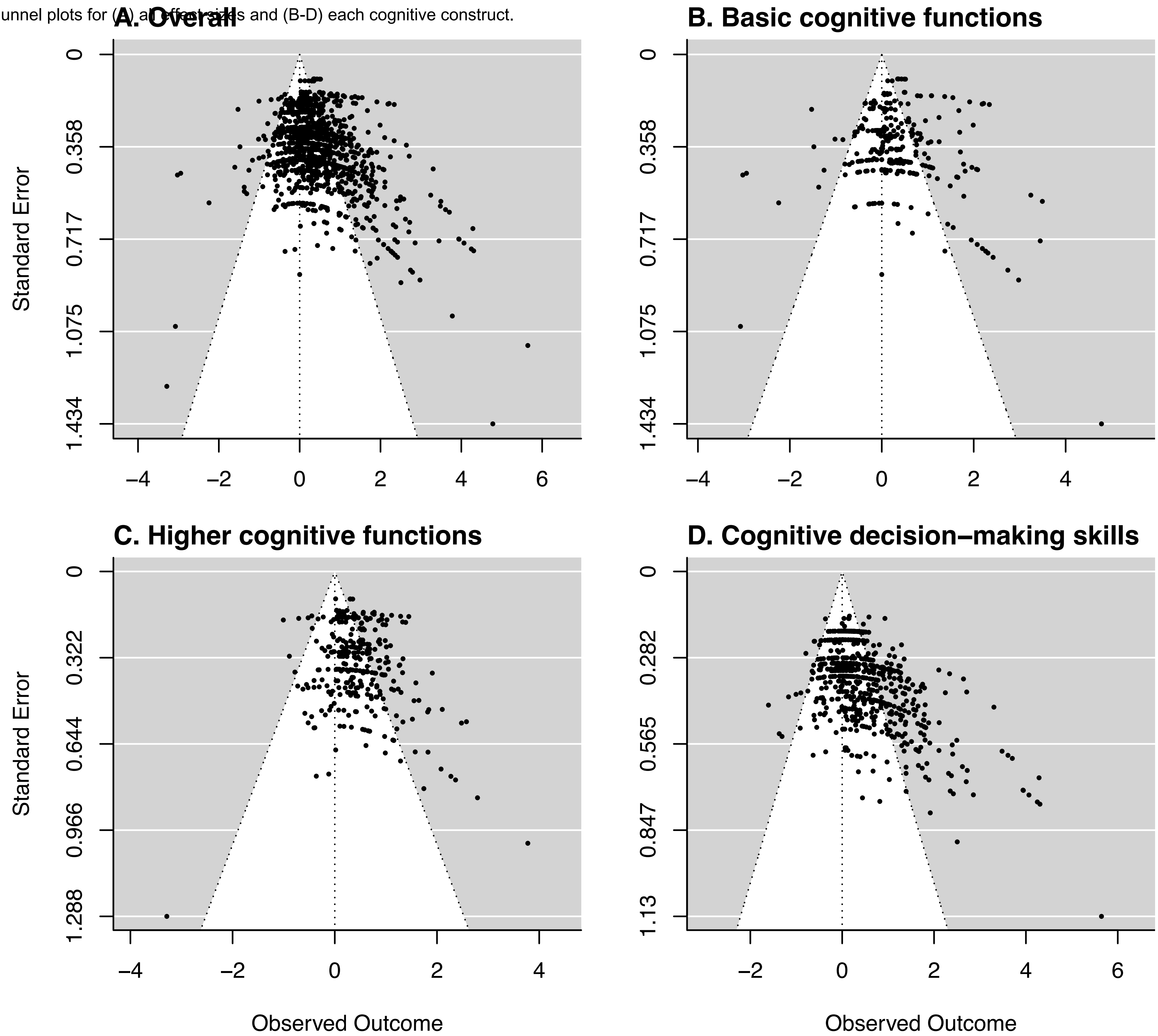
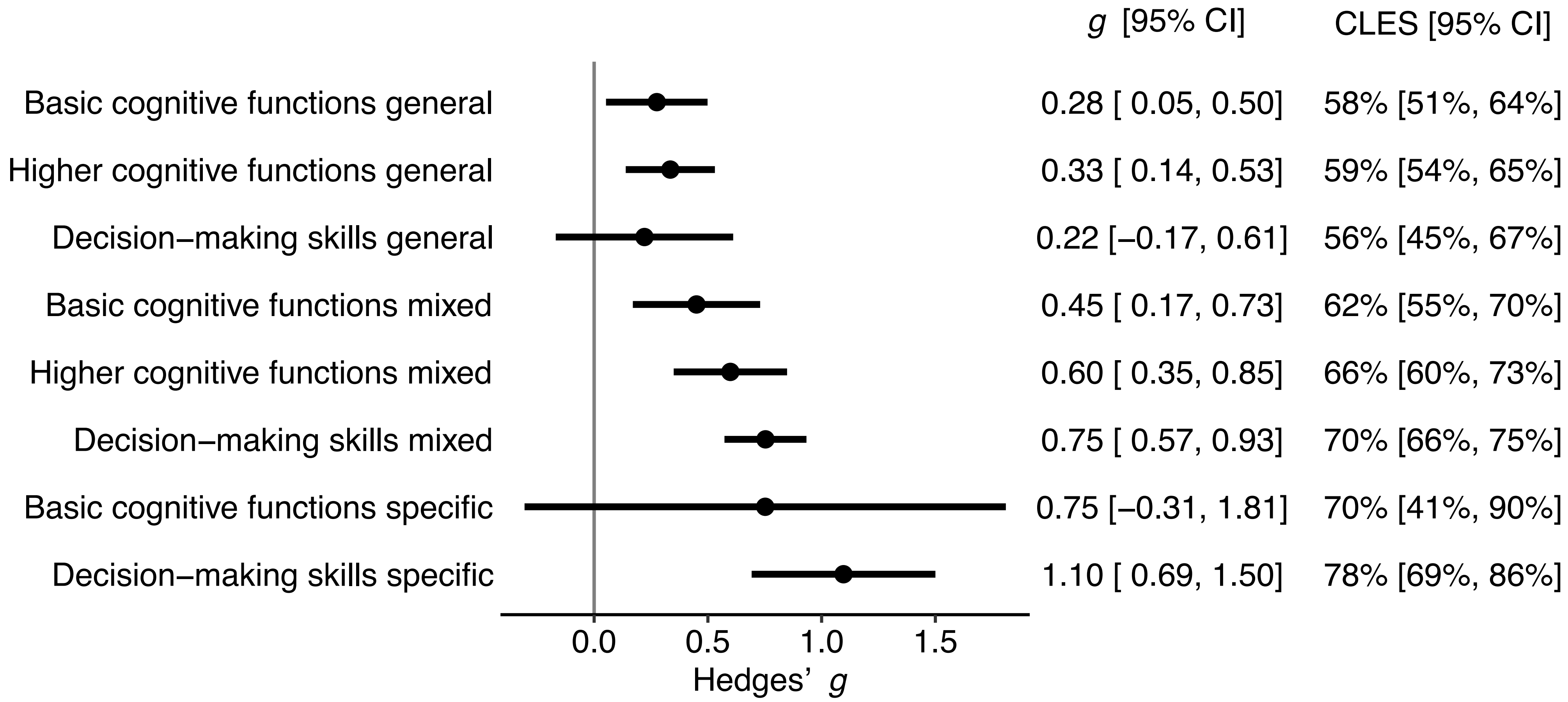
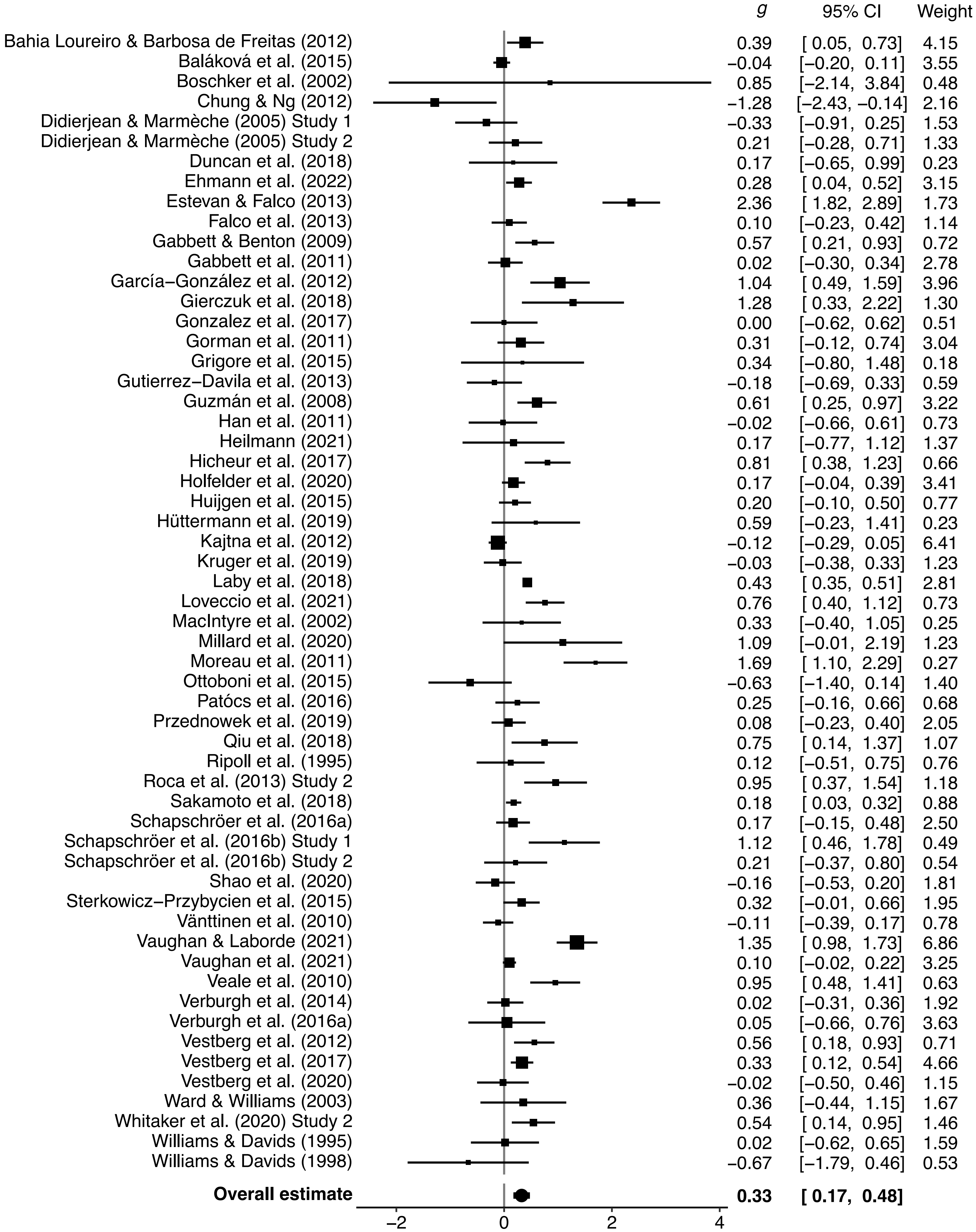


Figure 2. Funnel plots for (A) all effect sizes and (B-D) each cognitive construct.

Figure 3. Post-hoc subgroup analysis for combinations of cognitive constructs and specificity of tests.

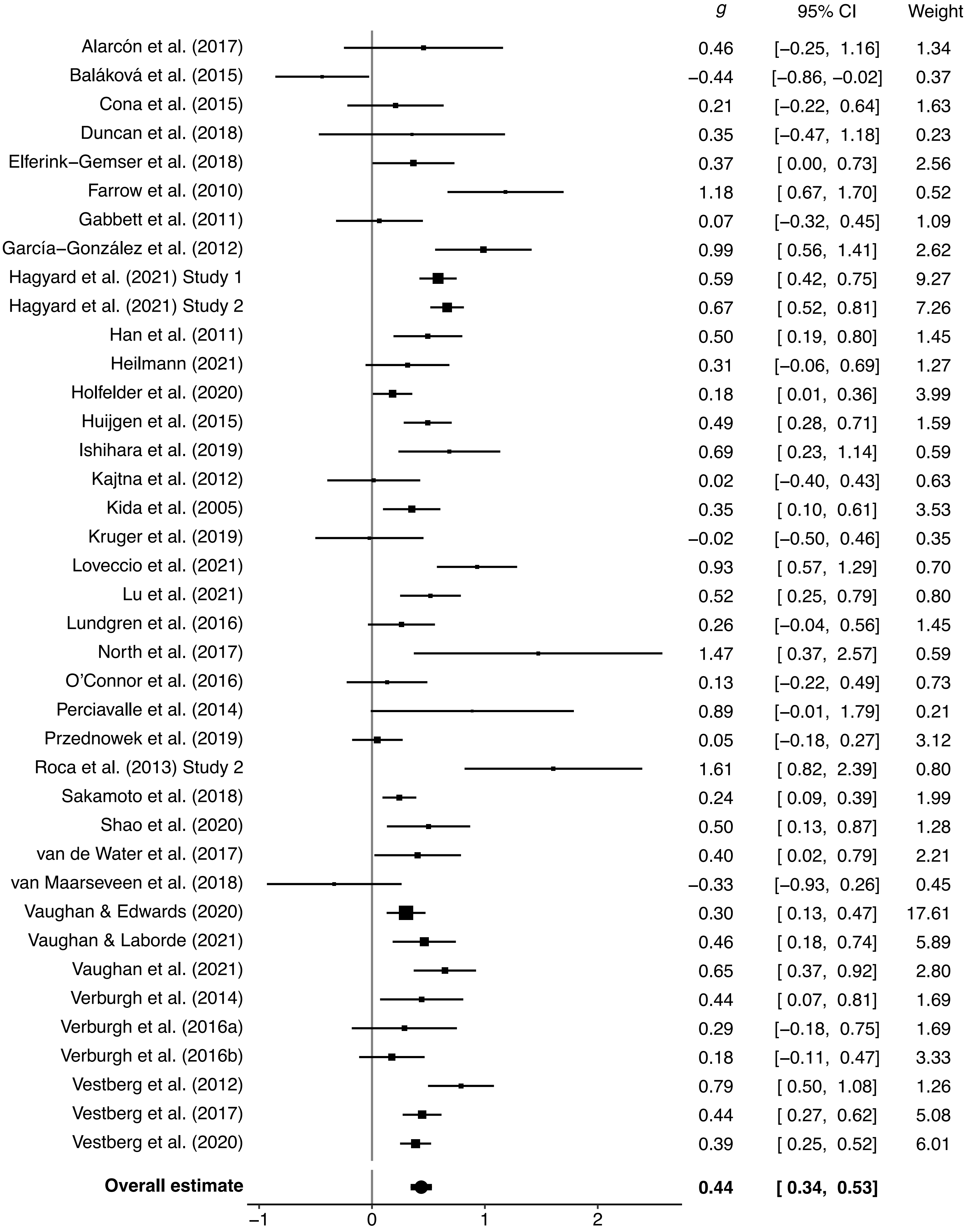


Appendix E. Forest plot of effect sizes basic cognitive functions.



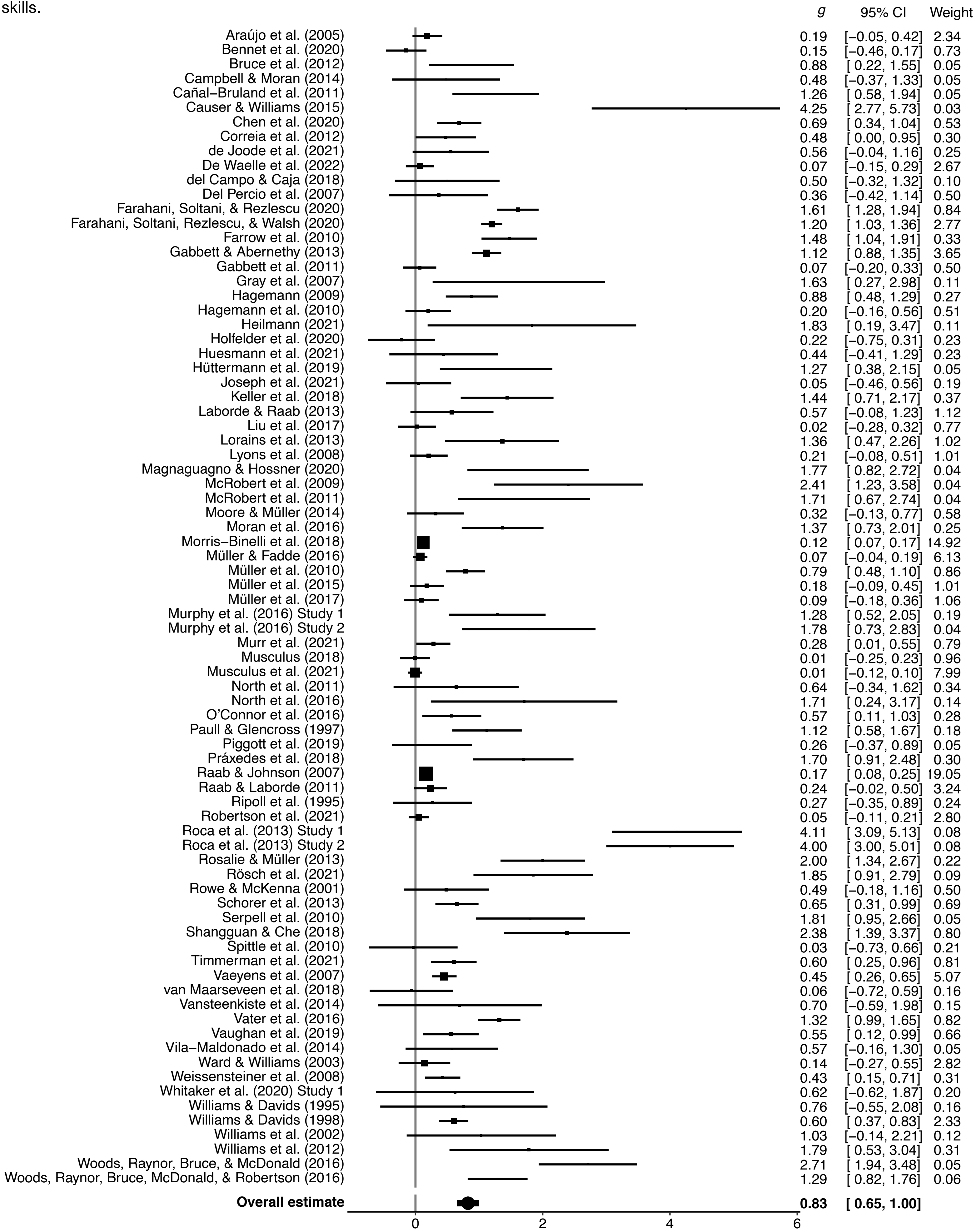
	g	95% CI	Weight
Bahia Loureiro & Barbosa de Freitas (2012)	0.39	[0.05, 0.73]	4.15
Baláková et al. (2015)	−0.04	[−0.20, 0.11]	3.55
Boschker et al. (2002)	0.85	[−2.14, 3.84]	0.48
Chung & Ng (2012)	−1.28	[−2.43, −0.14]	2.16
Didierjean & Marmèche (2005) Study 1	−0.33	[−0.91, 0.25]	1.53
Didierjean & Marmèche (2005) Study 2	0.21	[−0.28, 0.71]	1.33
Duncan et al. (2018)	0.17	[−0.65, 0.99]	0.23
Ehmann et al. (2022)	0.28	[0.04, 0.52]	3.15
Estevan & Falco (2013)	2.36	[1.82, 2.89]	1.73
Falco et al. (2013)	0.10	[−0.23, 0.42]	1.14
Gabbett & Benton (2009)	0.57	[0.21, 0.93]	0.72
Gabbett et al. (2011)	0.02	[−0.30, 0.34]	2.78
García−González et al. (2012)	1.04	[0.49, 1.59]	3.96
Gierczuk et al. (2018)	1.28	[0.33, 2.22]	1.30
Gonzalez et al. (2017)	0.00	[−0.62, 0.62]	0.51
Gorman et al. (2011)	0.31	[−0.12, 0.74]	3.04
Grigore et al. (2015)	0.34	[−0.80, 1.48]	0.18
Gutierrez−Davila et al. (2013)	−0.18	[−0.69, 0.33]	0.59
Guzmán et al. (2008)	0.61	[0.25, 0.97]	3.22
Han et al. (2011)	−0.02	[−0.66, 0.61]	0.73
Heilmann (2021)	0.17	[−0.77, 1.12]	1.37
Hicheur et al. (2017)	0.81	[0.38, 1.23]	0.66
Holfelder et al. (2020)	0.17	[−0.04, 0.39]	3.41
Huijgen et al. (2015)	0.20	[−0.10, 0.50]	0.77
Hüttermann et al. (2019)	0.59	[−0.23, 1.41]	0.23
Kajtna et al. (2012)	−0.12	[−0.29, 0.05]	6.41
Kruger et al. (2019)	−0.03	[−0.38, 0.33]	1.23
Laby et al. (2018)	0.43	[0.35, 0.51]	2.81
Loveccio et al. (2021)	0.76	[0.40, 1.12]	0.73
MacIntyre et al. (2002)	0.33	[−0.40, 1.05]	0.25
Millard et al. (2020)	1.09	[−0.01, 2.19]	1.23
Moreau et al. (2011)	1.69	[1.10, 2.29]	0.27
Ottoboni et al. (2015)	−0.63	[−1.40, 0.14]	1.40
Patócs et al. (2016)	0.25	[−0.16, 0.66]	0.68
Przednowek et al. (2019)	0.08	[−0.23, 0.40]	2.05
Qiu et al. (2018)	0.75	[0.14, 1.37]	1.07
Ripoll et al. (1995)	0.12	[−0.51, 0.75]	0.76
Roca et al. (2013) Study 2	0.95	[0.37, 1.54]	1.18
Sakamoto et al. (2018)	0.18	[0.03, 0.32]	0.88
Schapschröer et al. (2016a)	0.17	[−0.15, 0.48]	2.50
Schapschröer et al. (2016b) Study 1	1.12	[0.46, 1.78]	0.49
Schapschröer et al. (2016b) Study 2	0.21	[−0.37, 0.80]	0.54
Shao et al. (2020)	−0.16	[−0.53, 0.20]	1.81
Sterkowicz−Przybycien et al. (2015)	0.32	[−0.01, 0.66]	1.95
Vänttinen et al. (2010)	−0.11	[−0.39, 0.17]	0.78
Vaughan & Laborde (2021)	1.35	[0.98, 1.73]	6.86
Vaughan et al. (2021)	0.10	[−0.02, 0.22]	3.25
Veale et al. (2010)	0.95	[0.48, 1.41]	0.63
Verburgh et al. (2014)	0.02	[−0.31, 0.36]	1.92
Verburgh et al. (2016a)	0.05	[−0.66, 0.76]	3.63
Vestberg et al. (2012)	0.56	[0.18, 0.93]	0.71
Vestberg et al. (2017)	0.33	[0.12, 0.54]	4.66
Vestberg et al. (2020)	−0.02	[−0.50, 0.46]	1.15
Ward & Williams (2003)	0.36	[−0.44, 1.15]	1.67
Whitaker et al. (2020) Study 2	0.54	[0.14, 0.95]	1.46
Williams & Davids (1995)	0.02	[−0.62, 0.65]	1.59
Williams & Davids (1998)	−0.67	[−1.79, 0.46]	0.53
Overall estimate	**0.33**	**[0.17, 0.48]**	

Appendix F. Forest plot of effect sizes higher cognitive functions.



	g	95% CI	Weight
Alarcón et al. (2017)	0.46	[−0.25, 1.16]	1.34
Baláková et al. (2015)	−0.44	[−0.86, −0.02]	0.37
Cona et al. (2015)	0.21	[−0.22, 0.64]	1.63
Duncan et al. (2018)	0.35	[−0.47, 1.18]	0.23
Elferink−Gemser et al. (2018)	0.37	[0.00, 0.73]	2.56
Farrow et al. (2010)	1.18	[0.67, 1.70]	0.52
Gabbett et al. (2011)	0.07	[−0.32, 0.45]	1.09
García−González et al. (2012)	0.99	[0.56, 1.41]	2.62
Hagyard et al. (2021) Study 1	0.59	[0.42, 0.75]	9.27
Hagyard et al. (2021) Study 2	0.67	[0.52, 0.81]	7.26
Han et al. (2011)	0.50	[0.19, 0.80]	1.45
Heilmann (2021)	0.31	[−0.06, 0.69]	1.27
Holfelder et al. (2020)	0.18	[0.01, 0.36]	3.99
Huijgen et al. (2015)	0.49	[0.28, 0.71]	1.59
Ishihara et al. (2019)	0.69	[0.23, 1.14]	0.59
Kajtna et al. (2012)	0.02	[−0.40, 0.43]	0.63
Kida et al. (2005)	0.35	[0.10, 0.61]	3.53
Kruger et al. (2019)	−0.02	[−0.50, 0.46]	0.35
Loveccio et al. (2021)	0.93	[0.57, 1.29]	0.70
Lu et al. (2021)	0.52	[0.25, 0.79]	0.80
Lundgren et al. (2016)	0.26	[−0.04, 0.56]	1.45
North et al. (2017)	1.47	[0.37, 2.57]	0.59
O'Connor et al. (2016)	0.13	[−0.22, 0.49]	0.73
Perciavalle et al. (2014)	0.89	[−0.01, 1.79]	0.21
Przednowek et al. (2019)	0.05	[−0.18, 0.27]	3.12
Roca et al. (2013) Study 2	1.61	[0.82, 2.39]	0.80
Sakamoto et al. (2018)	0.24	[0.09, 0.39]	1.99
Shao et al. (2020)	0.50	[0.13, 0.87]	1.28
van de Water et al. (2017)	0.40	[0.02, 0.79]	2.21
van Maarseveen et al. (2018)	−0.33	[−0.93, 0.26]	0.45
Vaughan & Edwards (2020)	0.30	[0.13, 0.47]	17.61
Vaughan & Laborde (2021)	0.46	[0.18, 0.74]	5.89
Vaughan et al. (2021)	0.65	[0.37, 0.92]	2.80
Verburgh et al. (2014)	0.44	[0.07, 0.81]	1.69
Verburgh et al. (2016a)	0.29	[−0.18, 0.75]	1.69
Verburgh et al. (2016b)	0.18	[−0.11, 0.47]	3.33
Vestberg et al. (2012)	0.79	[0.50, 1.08]	1.26
Vestberg et al. (2017)	0.44	[0.27, 0.62]	5.08
Vestberg et al. (2020)	0.39	[0.25, 0.52]	6.01
Overall estimate	**0.44**	**[0.34, 0.53]**	

Appendix G. Forest plot of effect sizes cognitive decision-making skills.



	g	95% CI	Weight
Araújo et al. (2005)	0.19	[−0.05, 0.42]	2.34
Bennet et al. (2020)	0.15	[−0.46, 0.17]	0.73
Bruce et al. (2012)	0.88	[0.22, 1.55]	0.05
Campbell & Moran (2014)	0.48	[−0.37, 1.33]	0.05
Cañal−Bruland et al. (2011)	1.26	[0.58, 1.94]	0.05
Causer & Williams (2015)	4.25	[2.77, 5.73]	0.03
Chen et al. (2020)	0.69	[0.34, 1.04]	0.53
Correia et al. (2012)	0.48	[0.00, 0.95]	0.30
de Joode et al. (2021)	0.56	[−0.04, 1.16]	0.25
De Waelle et al. (2022)	0.07	[−0.15, 0.29]	2.67
del Campo & Caja (2018)	0.50	[−0.32, 1.32]	0.10
Del Percio et al. (2007)	0.36	[−0.42, 1.14]	0.50
Farahani, Soltani, & Rezlescu (2020)	1.61	[1.28, 1.94]	0.84
Farahani, Soltani, Rezlescu, & Walsh (2020)	1.20	[1.03, 1.36]	2.77
Farrow et al. (2010)	1.48	[1.04, 1.91]	0.33
Gabbett & Abernethy (2013)	1.12	[0.88, 1.35]	3.65
Gabbett et al. (2011)	0.07	[−0.20, 0.33]	0.50
Gray et al. (2007)	1.63	[0.27, 2.98]	0.11
Hagemann (2009)	0.88	[0.48, 1.29]	0.27
Hagemann et al. (2010)	0.20	[−0.16, 0.56]	0.51
Heilmann (2021)	1.83	[0.19, 3.47]	0.11
Holfelder et al. (2020)	0.22	[−0.75, 0.31]	0.23
Huesmann et al. (2021)	0.44	[−0.41, 1.29]	0.23
Hüttermann et al. (2019)	1.27	[0.38, 2.15]	0.05
Joseph et al. (2021)	0.05	[−0.46, 0.56]	0.19
Keller et al. (2018)	1.44	[0.71, 2.17]	0.37
Laborde & Raab (2013)	0.57	[−0.08, 1.23]	1.12
Liu et al. (2017)	0.02	[−0.28, 0.32]	0.77
Lorains et al. (2013)	1.36	[0.47, 2.26]	1.02
Lyons et al. (2008)	0.21	[−0.08, 0.51]	1.01
Magnaguagno & Hossner (2020)	1.77	[0.82, 2.72]	0.04
McRobert et al. (2009)	2.41	[1.23, 3.58]	0.04
McRobert et al. (2011)	1.71	[0.67, 2.74]	0.04
Moore & Müller (2014)	0.32	[−0.13, 0.77]	0.58
Moran et al. (2016)	1.37	[0.73, 2.01]	0.25
Morris−Binelli et al. (2018)	0.12	[0.07, 0.17]	14.92
Müller & Fadde (2016)	0.07	[−0.04, 0.19]	6.13
Müller et al. (2010)	0.79	[0.48, 1.10]	0.86
Müller et al. (2015)	0.18	[−0.09, 0.45]	1.01
Müller et al. (2017)	0.09	[−0.18, 0.36]	1.06
Murphy et al. (2016) Study 1	1.28	[0.52, 2.05]	0.19
Murphy et al. (2016) Study 2	1.78	[0.73, 2.83]	0.04
Murr et al. (2021)	0.28	[0.01, 0.55]	0.79
Musculus (2018)	0.01	[−0.25, 0.23]	0.96
Musculus et al. (2021)	0.01	[−0.12, 0.10]	7.99
North et al. (2011)	0.64	[−0.34, 1.62]	0.34
North et al. (2016)	1.71	[0.24, 3.17]	0.14
O'Connor et al. (2016)	0.57	[0.11, 1.03]	0.28
Paull & Glencross (1997)	1.12	[0.58, 1.67]	0.18
Piggott et al. (2019)	0.26	[−0.37, 0.89]	0.05
Práxedes et al. (2018)	1.70	[0.91, 2.48]	0.30
Raab & Johnson (2007)	0.17	[0.08, 0.25]	19.05
Raab & Laborde (2011)	0.24	[−0.02, 0.50]	3.24
Ripoll et al. (1995)	0.27	[−0.35, 0.89]	0.24
Robertson et al. (2021)	0.05	[−0.11, 0.21]	2.80
Roca et al. (2013) Study 1	4.11	[3.09, 5.13]	0.08
Roca et al. (2013) Study 2	4.00	[3.00, 5.01]	0.08
Rosalie & Müller (2013)	2.00	[1.34, 2.67]	0.22
Rösch et al. (2021)	1.85	[0.91, 2.79]	0.09
Rowe & McKenna (2001)	0.49	[−0.18, 1.16]	0.50
Schorer et al. (2013)	0.65	[0.31, 0.99]	0.69
Serpell et al. (2010)	1.81	[0.95, 2.66]	0.05
Shangguan & Che (2018)	2.38	[1.39, 3.37]	0.80
Spittle et al. (2010)	0.03	[−0.73, 0.66]	0.21
Timmerman et al. (2021)	0.60	[0.25, 0.96]	0.81
Vaeyens et al. (2007)	0.45	[0.26, 0.65]	5.07
van Maarseveen et al. (2018)	0.06	[−0.72, 0.59]	0.16
Vansteenkiste et al. (2014)	0.70	[−0.59, 1.98]	0.15
Vater et al. (2016)	1.32	[0.99, 1.65]	0.82
Vaughan et al. (2019)	0.55	[0.12, 0.99]	0.66
Vila−Maldonado et al. (2014)	0.57	[−0.16, 1.30]	0.05
Ward & Williams (2003)	0.14	[−0.27, 0.55]	2.82
Weissensteiner et al. (2008)	0.43	[0.15, 0.71]	0.31
Whitaker et al. (2020) Study 1	0.62	[−0.62, 1.87]	0.20
Williams & Davids (1995)	0.76	[−0.55, 2.08]	0.16
Williams & Davids (1998)	0.60	[0.37, 0.83]	2.33
Williams et al. (2002)	1.03	[−0.14, 2.21]	0.12
Williams et al. (2012)	1.79	[0.53, 3.04]	0.31
Woods, Raynor, Bruce, & McDonald (2016)	2.71	[1.94, 3.48]	0.05
Woods, Raynor, Bruce, McDonald, & Robertson (2016)	1.29	[0.82, 1.76]	0.06
Overall estimate	**0.83**	**[0.65, 1.00]**	