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REVIEW ARTICLE OPEN ACCESS

Determining Cognitive Performance in Athletes: A Systematic Review Focused on Methodology of Applying Cognitive Tests

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ABSTRACT

Although in recent years, there have been many studies to determine the cognitive performance of athletes, there are significant differences in the methodological approaches of these studies. Therefore, this methodology-focused systematic review aims to analyze the application methods of cognitive test studies with athletes and to provide standard recommendations for further studies. For this purpose, three electronic databases (Web of Science, PubMed, and Scopus) were searched using predetermined keywords. As a result of the screening, 25 studies were included in the review. The result of this systematic review focused on the methodology of applying cognitive tests and observed considerable heterogeneity in methodological procedures applied in studies investigating the cognitive performance of athletes. The findings of this review highlight the need for the development of standardized procedures for the assessment of cognitive performance in future research while offering practical recommendations for researchers and coaches working in this area.

1 | Introduction

Daily, we perform complex activities that require a wide range of cognitive functions to interact with the environment. Moreover, well-developed cognitive functions are not only essential for mental and physical health, success in school and work, and social and psychological development, but also for sports and competitive performance (Diamond 2013; Furley and Memmert 2010; Scharfen and Memmert 2019; Vestberg et al. 2017). To assess cognitive performance, various tests have been developed and applied to probe cognitive functions (e.g., neuropsychological tests) and to understand whether they influence or predict (elite) sports performance (Logan et al. 2022; Scharfen and Memmert 2019). Although there is an emerging

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Summary

- There is a lack of standardization in the application of cognitive tests in the field of exercise and cognition.
- More research is needed on the application of cognitive tests in the field of exercise and cognition.
- Created "Preferred reporting items for cognitive factors assessing studies checklist" may lead the researchers to enhance the quality of the methods section in future studies.

body of work that has incorporated neuroimaging assessment approaches, most of the literature has relied upon behavioral indices obtained from cognitive tests (e.g., reaction time and accuracy scores) (Burstein et al. 2021; Ergonul et al. 2019; Gökçe et al. 2021; Gümüş et al. 2020; Lichstein et al. 2000; Mancı et al. 2021). In addition to physiological requirements, there is a growing amount of evidence that suggests that highly developed cognitive functions are key to attaining individual elite athlete performance and achieving success in sportive competitions, especially in team sports such as basketball, football, and handball (Furley and Memmert 2010; Perrey 2020; Scharfen and Memmert 2019; Vestberg et al. 2017).

In this context, there are two prominent approaches to studying the relationships between cognitive performance and sports performance, namely the expert performance approach (Mann et al. 2007; Scharfen and Memmert 2019) and the cognitive component approach (Scharfen and Memmert 2019; Voss et al. 2010). While the expert performance approach focuses on examining the athletes' perceptual-cognitive skills in a sport-specific context (i.e., ecologically valid context) (Mann et al. 2007; Scharfen and Memmert 2019), the cognitive component approach investigates associations between sports performance by using standardized cognitive tests that probe cognitive abilities (e.g., Memory, information processing, and attention) and executive functions (e.g., Inhibition, cognitive flexibility, and working memory) (Salthouse 2005; Scharfen and Memmert 2019; Voss et al. 2010).

To successfully compete at an elite level, it is assumed that athletes need to be equipped with high-level skills in several general cognitive domains, including but not limited to cognitive control, information processing, and attention (Scharfen and Memmert 2019). For example, a successful basketball player needs to observe the play area thoroughly during the game (i.e., requiring visual attention), make the right decision considering numerous variables (e.g., requiring cognitive control, information processing, and working memory to remember the defensive players' position, and open teammate while considering the shot clock), and generate a fast and accurate response by translating the perceptual information via cognitive functions in an appropriate motor response (Jakovljević et al. 2015; Mancı et al. 2023). Studies have shown that elite athletes perform better than amateur athletes, require fewer cortical resources, and that athletes who participate in team sports have better performance (Babiloni et al. 2010; Del Percio et al. 2009; Scharfen and Memmert 2019; Logan et al. 2022).

Despite the multifaceted and dynamic nature of situations in sports settings, cognitive tests and test batteries developed for assessments in patient populations such as those with developmental disabilities and/or mild cognitive impairment are often used to evaluate the cognitive performance of athletes (Banich and Compton 2018; Furley et al. 2023; Maroon et al. 2000). However, it is unclear whether these cognitive tests and test batteries are well-situated to predict sports performance in athletes (Furley et al. 2023). Large heterogeneity in existing studies can make comparisons across studies challenging and thus might hinder progress in both theoretical and practical applications. In addition to applying cognitive tests with insufficient validity (e.g., to predict sports performance), inconsistent or incomplete information about the methodological details of their application may also limit (i.e., modifications to cognitive tests without specifying what has changed or the number of times the cognitive test was performed, etc.) the progress in this research field. To address this gap in the literature, this systematic review aims to summarize the methodological details of studies assessing cognitive performance in athlete populations to develop recommendations that guide and improve future research in this field.

In this context, we developed a checklist based on the critical reflection on methodological details provided in the reviewed studies and the broader literature on cognitive testing to guide future studies regarding the application and reporting of cognitive testing in athlete populations. This will hopefully contribute to increasing the quality of evidence in this field.

2 | Materials and Methods

2.1 | Search Strategy and Process

A systematic review was conducted by E.M., U.G., and F.Ö. up to 2024, according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement guidelines (Moher et al. 2009; Page et al. 2021), using the databases PubMed, Scopus, and Web of Science (Figure 1). The following search string, which is based on recent systematic reviews in this research field (Heilmann et al. 2022; Logan et al. 2022; Scharfen and Memmert 2019), was used: (["executive function"] OR ["executive performance"] OR ["cognitive performance"] OR ["cognitive test"]) AND (["acute exercise"] OR ["chronic exercise"] OR ["athletes"] OR ["athletics"] OR ["sports"]). For all searches, we used the following exclusion parameters, NOT disability NOT concussion NOT disease NOT injury NOT patients NOT mental illness NOT nutrition NOT neuroimaging NOT treatment NOT sleep (with Title/Abstract/Keywords). During the search, the following filters were applied: full-text articles (i.e., no conference proceedings) published between 2012 and 2024 (in July), human research, and written in the English language. Afterward, the results of the systematic search were loaded into a citation manager (EndNote 20.2.1., Philadelphia), which was used for further analyses and removing duplicates. Records were screened by title, abstract, and keywords, and then the full text was evaluated by three independent investigators (E.M, U.G, and F.Ö). The current study is registered with the Open Science Framework (linked in title page.).

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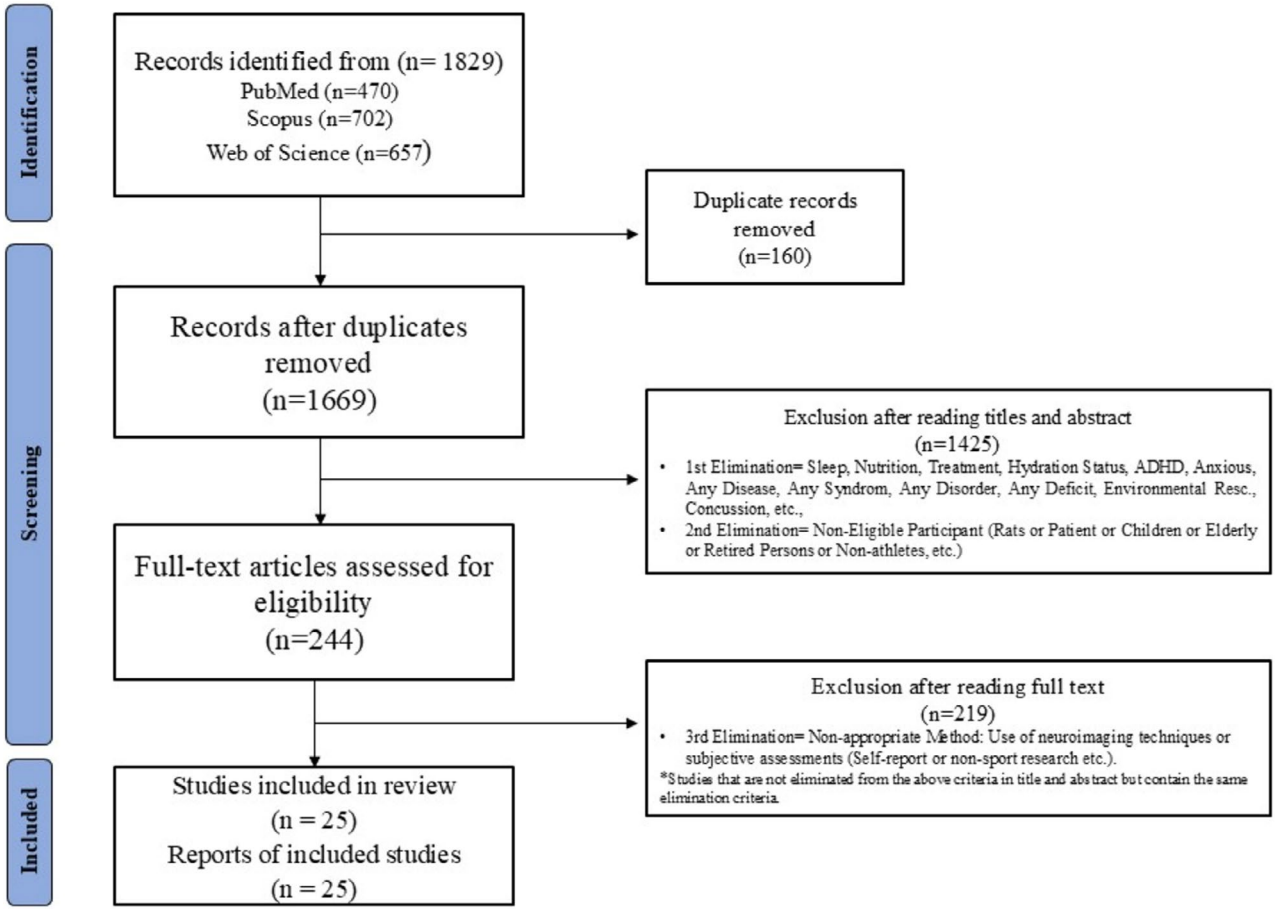


FIGURE 1 | PRISMA flow diagram presenting search strategy.

2.2 | Inclusion and Exclusion Criteria

The inclusion and exclusion criteria were determined according to the «PICOS» principle (Harris et al. 2014; Moher et al. 2009), which is an acronym for participants (P), intervention (I), comparisons (C), outcomes (O), and study design (S).

2.2.1 | Participants (P)

We include studies that are specifically focused on athletes [≥ 18 years, can be classified as active and trained/developmental athletes (i.e., ≥ Tier 2 in the classification approach of McKay and colleagues), (McKay et al. 2022)] and thus excluded all studies with populations other than athletes (e.g., children, or older adults).

2.2.2 | Intervention (I)

We included all studies regardless of whether they conducted an acute or chronic physical exercise or not (see also the section "*Study design*") but excluded all studies investigating the influence of other treatments (e.g., pharmacological interventions) or the influence of environmental conditions (e.g., exposure to heat or hypoxia).

2.2.3 | Comparisons (C)

There are no specific inclusion and exclusion criteria concerning the comparison group.

2.2.4 | Outcomes (O)

We consider studies as relevant that probe cognitive performance by assessing behavioral indices (e.g., reaction times, accuracy) in standardized cognitive tests (e.g., Stroop test), but do not include studies that simultaneously apply neuroimaging techniques. The latter exclusion criterion was motivated by the fact that when cognitive tests are adapted to meet the needs of a specific neuroimaging modality (e.g., using a block- or event-related design, which requires, for instance, the adaptation of interstimulus intervals) so that such cognitive tests are not necessarily fully comparable to solely behavioral assessments.

2.2.5 | Study Design (S)

We included both cross-sectional studies and interventional studies (e.g., conducting an acute bout of physical exercise). In this context, we define physical exercise, based on the American

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College of Sports Medicine (ACSM's 2010), as "a type of physical activity consisting of planned, structured, and repetitive bodily movement done to improve or maintain one or more components of physical fitness."

In addition, only studies that (i) were published between 2012 and 2024 and (ii) were written in the English language were included, whereas publications other than original investigations (e.g., case studies and reviews) were excluded.

We limited our systematic review to articles published between 2012 and 2024 (in July) as we aim to provide an overview of the most recent studies investigating cognitive performance in athlete populations. Furthermore, since this systematic literature review aims to analyze the methodological details of the relevant studies, only studies that used an objective and standardized cognitive test (e.g., via paper-pencil or computer-based versions) were included because other approaches (i.e., verbal or self-report techniques) can have a higher risk of bias depending on their application.

Following the literature review, the following information was extracted by three independent reviewers from the reviewed studies: (i) the authors of the study, (ii) the year of publication, (iii) the number and characteristics of the participants, (iv) information on the applied cognitive test including the assessed cognitive domain, and environmental conditions, and (v) a summary of the outcomes (See Table 1). Furthermore, we also inspected the methodological details from the published studies and developed a checklist for future studies aiming to investigate cognitive performance in athletes (See Table 2).

No risk of bias assessment was conducted because this systematic review focused on the methodological details of the studies rather than their findings. Furthermore, we did not contact the corresponding authors whose articles are missing information. All articles were independently screened and assessed by three authors. After the screening, the same three authors discussed potential disagreements on studies and resolved them via consensus.

3 | Results

Our search in the three electronic databases yielded 1829 documents in the initial identification phase of potentially relevant studies. After the automatic duplicate removal, 1669 records remained, and by title and abstract screening, 244 records were deemed potentially relevant to the present review. After the full-text screening, 219 studies were excluded mainly based on the following reasons: (i) use of neuroimaging techniques, (ii) nonathletes group, (iii) study that primarily focused on the influence of sleep, nutrition, treatment, hydration, or mental health, or (iv) study that focused on the influence of environmental factors. Finally, 25 studies met the eligibility criteria and were included. A summary of the search and selection process in a flow diagram is presented in Figure 1. In the following sections, we summarize the results of the 25 studies that have been found eligible and from which specific data were extracted during the review process. For a comprehensive overview, we refer to the reader to Table 1, where the findings were also tabulated chronologically. In addition, the limitations of the studies and recommendations for improving these limitations are summarized in Table 3.

3.1 | Cognitive Tests

Ten studies used the "Stroop Test" (*reported that it is associated with processing speed, executive control, selective attention, and the ability to inhibit habitual responses*), (Chang et al. 2014; Coco et al. 2020; Costello et al. 2023; Kuroda et al. 2023; Lopes et al. 2020; Malcolm et al. 2022; Paul et al. 2024; Rincón-Campos et al. 2019; Shields et al. 2017; Chang et al. 2017), four studies used the "Trail Making Test" (*reported that it is associated with visual search, set-shifting, and cognitive flexibility*), (Coco et al. 2020; Knöllner et al. 2022; Rincón-Campos et al. 2019; Yongtawee et al. 2022), "Stop Signal Task" (*reported that it is associated with proactive and reactive inhibition*), (Brevers et al. 2018; Knöllner et al. 2022; Liao et al. 2017; Vaughan and Edwards 2020), and Flanker Task (*reported that it is associated with working memory, inhibitory control, and reaction time*), (Campanella et al. 2024; Gutiérrez-Capote et al. 2024; Shao et al. 2020; Yongtawee et al. 2022), three studies used the "Simple Reaction Time Test" (*reaction time*), (Azevedo and Carpes 2021; Coco et al. 2020; Yongtawee et al. 2022), two studies used the "Corsi's Block Test" (*reported that it is associated with reaction time and visuospatial short-term working memory*), (Costello et al. 2023; Malcolm et al. 2022), and one study used "Design Fluency" (*reported that it is associated with inhibitory control, and cognitive flexibility*), (Yongtawee et al. 2022), test were used (Figure 2a).

Ten studies used one cognitive test (Brevers et al. 2018; Chang et al. 2014; Kapur and Joshi 2024; Kuroda et al. 2023; Liao et al. 2017; Lopes et al. 2020; Rahimi et al. 2022; Shao et al. 2020; Shields et al. 2017; Wang et al. 2016), six studies used two tests (Azevedo and Carpes 2021; Campanella et al. 2024; Costello et al. 2023; González-Fernández et al. 2024; Gutiérrez-Capote et al. 2024; Paul et al. 2024), four studies used 3 cognitive tests (Coco et al. 2020; Manci et al., 2023; Rincón-Campos et al. 2019; Vaughan and Edwards 2020), three studies used 4 tests (Knöllner et al. 2022; MacDonald and Minahan 2016; Malcolm et al. 2022), and one study used 5 (Chang et al. 2017), and one study used 6 cognitive tests (Yongtawee et al. 2022) (Figure 2c).

3.2 | Tools/Platforms Used for the Cognitive Assessment

Ten studies included in our review did not specify through which program or platform the tests were administered (Chang et al. 2017; Coco et al. 2020; González-Fernández et al. 2024; Kapur and Joshi 2024; Liao et al. 2017; Malcolm et al. 2022; Paul et al. 2024; Rahimi et al. 2022; Rincón-Campos et al. 2019; Campanella et al. 2024). In the studies where this information has been presented, a wide variety of applications, platforms, or programs are used to administer cognitive tests (Figure 2b). In the reviewed studies, E-Prime (Shao et al. 2020; Shields et al. 2017), CANTAB (Knöllner et al. 2022; Vaughan and Edwards 2020), PsychoPy (Azevedo and Carpes 2021; Lopes et al. 2020), and the Psychtoolbox battery (Brevers et al. 2018; Wang et al. 2016) were used for cognitive testing. In the other

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TABLE 1 | An overview of participant characteristics, cognitive testing, and environmental conditions, as well as the key findings of the studies, included a review.

First author (year)	(1.) Participants' characteristics (2.) Number of participants'	(1.) Number of cognitive tests (2.) Order of cognitive tests (if $n>1$) (3.) Familiarization (Number of trials/accuracy)	Type of cognitive test (Cognitive domain as described in the study^)	Methodological characteristics (1.) Tools or Platform used for cognitive testing. (2.) Screen size (") and characteristics (3.) Distance and position of the screen (4.) Environmental condition	Other measures	Effects of cognitive performance, mental fatigue, and exhaustion time
Studies Conducting an Acute Bout of Physical Exercise						
Chang et al. (2014)	(1.) Healthy college adults with low, moderate, and high fitness group	(1.) $n=1$	Stroop Test (processing speed, executive control, selective attention, and the ability to inhibit habitual responses)	(1.) Neuroscan System		After cycling versus prior cycling:
	(2.) $n=36$	(2.) N.A.		(2.) 21"	Exercise test, HR, RER and RPE	– Cognitive performance (measured by RT) (in all groups)
		(3.) Until their accuracy reached 90%		(3.) N.A.		Low-moderate-high fit groups:
				(4.) N.A.		– No significant difference in RT on Stroop (congruent condition)
						– RT on Stroop for high fit group (incongruent condition)
Lopes et al. (2020)	(1.) Brazilian professional mid- and long-distance endurance runners (2.) $n=35$	(1.) $n=1$	Stroop Test (RT, lapses of attention, and accuracy) & control condition (watched a 45-min documentary)	(1.) PsychoPy	Aerobic fitness tests, Athletic performance score, VAS, BORG, HR, BRUMS	Pretest versus posttest:

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First author (year)	(1.) Participants' characteristics (2.) Number of participants'	(1.) Number of cognitive tests (2.) Order of cognitive tests (if $n>1$) (3.) Familiarization (Number of trials/accuracy)	Type of cognitive test (Cognitive domain as described in the study^)	Methodological characteristics (1.) Tools or Platform used for cognitive testing. (2.) Screen size (") and characteristics (3.) Distance and position of the screen (4.) Environmental condition	Other measures	Effects of cognitive performance, mental fatigue, and exhaustion time
		(2.) N.A.		(2.) N.A.		– Increased mental fatigue (via Stroop Task) reduces cognitive performance and exhaustion time for men and women
		(3.) N.A.		(3.) N.A.		
				(4.) N.A.		Stroop task versus control:
						– Perception of effort in Stroop task for women
						– Exhaustion time in Stroop task for men and women
Malcolm et al. (2022)	(1.) Hockey players (2.) $n=37$	(1.) $n=4$	Visual Search Test (Perception), Stroop Test (Executive Function), Corsi Blocks (Memory), and Rapid Visual Information Processing (Attention)	(1.) N.A.	BRUMS, HR, Blood Analyses, GPS, Hydration Status	Pretest versus half time and full-time tests:
		(2.) In the order stated in the next column ...		(2.) 14″		– Working memory (RT) at half-time compared to pretest
		(3.) Participants all completed one familiarization session (3–6 practice stimuli)		(3.) N.A.		Match versus control trials:

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				(4.) Participants spaced around the room and wore noise-canceling headphones to eradicate any distracting stimuli & Temperature: 10.3°C ± 2.7°C		– Working memory (RT) at full-time on match trial compared to pretest Trial time interaction: – RT on Stroop test on match trial at half-time compared to the control trial and pretest – Working memory (RT) on match trial at full-time compared to the control and pretest – No significant difference in accuracy on visual search and Stroop test
Kuroda et al. (2023)	(1.) Male tennis players (2.) $n = 11$	(1.) $n = 1$ (2.) N.A.	MV. Stroop Color and Word Test (cognitive processing and inhibitory control)	(1.) Paper Version (2.) N.A.	HR, RPE, Serve Accuracy	30-min tennis exercise program and Pre versus Posttest: – Executive function (RT and accuracy) when playing tennis are positively associated with the accuracy of the second serve

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First author (year)	(1.) Participants' characteristics (2.) Number of participants'	(1.) Number of cognitive tests (2.) Order of cognitive tests (if $n>1$) (3.) Familiarization (Number of trials/accuracy)	Type of cognitive test (Cognitive domain as described in the study^)	Methodological characteristics (1.) Tools or Platform used for cognitive testing. (2.) Screen size (") and characteristics (3.) Distance and position of the screen (4.) Environmental condition	Other measures	Effects of cognitive performance, mental fatigue, and exhaustion time
		(3.) N.A.		(3.) N.A.		
				(4.) N.A.		
Gutiérrez-Capote et al. (2024)	(1.) University students (2.) $n=44$	(1.) $n=2$	Flanker Task (interference control) and Go-No go (inhibition)	(1.) PEBL	HR, Sports training experience	Different 1×1 basketball practice rules
		(2.) N.A.		(2.) 22″		– Increasing motor complexity (more rules) worsened inhibitory control (accuracy) and RT
		(3.) 10 practice trials		(3.) 60-cm viewing distance		– Increased sport experience has positively impacted RT and accuracy
				(4.) Black background and quiet room		
Studies Conducting Chronic Physical Exercises						
Shields et al. (2017)	(1.) Division I Rowers (2.) Rowers $n=43$ controls $n=23$	(1.) $n=1$		(1.) E-Prime	Salivary cortisol, VAS, ESS, PDQ, PSS, TMD, POMS	Baseline versus typical training, peak training, and recovery testing times:
		(2.) N.A.	Stroop Test (sustained attention task)	(2.) 19″		– PSS at typical and peak training tests compared to baseline and recovery tests
		(3.) Four blocks of 25 trials		(3.) N.A.		– TMD at typical and peak training tests compared to baseline and recovery tests
				(4.) N.A.		

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Rincon-Campos et al., (2019)	(1.) Semiprofessional football players (2.) $n=28$	(1.) $n=3$	MoCA (executive functions, visuospatial ability, memory, attention, concentration, working memory, language, and orientation), Trail Making Test (visual search speed, scanning, attention, sequencing, and cognitive flexibility), Stroop Test (inhibit an automatic response and select a response)	(1.) N.A.	Beck Depression Inventory-II and Generalized Anxiety Disorder Questionnaire- 7	Posttest versus pretest:
		(2.) N.A.		(2.) N.A.		– Inhibition, planning, attention, and motor impulsiveness
		(3.) N.A.		(3.) N.A.		– Need thwarting
				(4.) In classrooms (good lighting, and air conditioning) and at specific times (morning/evening)		– Relationship between executive function, impulsiveness, psychological needs, and affective symptoms
Azevedo and Carpes 2021	(1.) Professional male futsal players	(1.) $n=2$	Simple RT (RT) and Selective Attention (Attention and inhibition)	(1.) PsychoPy	VO_{2max}, Jump Power, Dynamometry (*Muscular strength*), RPE	Low load and high load accumulated

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	(2.) $n=11$	(2.) N.A.		(2.) 14"		Long-term training program:
		(3.) N.A.		(3.) 1 m away at eyes level		– Poor cognitive performance (RT and selective attention) was directly related to the perception of effort at a greater extent
				(4.) Controlled temperature and noise environment		
Costello et al. (2023)	(1.) Well-trained male endurance cyclists (2.) $n=23$	(1.) $n=2$	Stroop Test (processing speed, executive control, selective attention, and the ability to inhibit habitual responses), Corsi block task (RT and, visuospatial short-term working memory)	(1.) COMPASS	POMS, Perceived sleep quality, Cycling performance tests, Assessment of overreaching	Baseline versus TrW1, TrW2, TaW1, and TaW2 tests:
		(2.) N.A.		(2.) N.A.		– No significant difference in RT, inhibitory control, and visuospatial short-term working memory
		(3.) N.A.		(3.) N.A.		
				(4.) Isolated booth with noise-minimizing headphones to minimize visual and noise distraction.		

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TABLE 1 | (Continued)

First author (year)	(1.) Participants' characteristics (2.) Number of participants'	(1.) Number of cognitive tests (2.) Order of cognitive tests (if $n > 1$) (3.) Familiarization (Number of trials/accuracy)	Type of cognitive test (Cognitive domain as described in the study^)	Methodological characteristics (1.) Tools or Platform used for cognitive testing. (2.) Screen size (") and characteristics (3.) Distance and position of the screen (4.) Environmental condition	Other measures	Effects of cognitive performance, mental fatigue, and exhaustion time
González-Fernández et al. (2024)	(1.) Female soccer players	(1.) $n = 2$	Psychomotor Vigilance Task (PVT) and Sustained attention to respond task (SART)	(1.) Phone	CMJ, HR, Yo-yo intermittent recovery test, Anthropometric measurements	8 Weeks preseason training pre and postmeasurements
	(2.) $n = 16$	(2.) N.A.		(2.) 4" (phone screen)		– 8 weeks preseason training induced significant improvements on cognitive performance [shorter RT (for PVT) and better accuracy (for SART)] of female soccer players
		(3.) N.A.		(3.) 50–90 cm away at eyes level		
				(4.) Controlled temperature (22°C—52%) and noise environment		
Campanella et al. (2024)	(1.) Elite judo athletes	(1.) $n = 2$	MV. Flanker task (working memory, inhibitory control, and cognitive flexibility) and Digit Span (working memory)	(1.) Computer	Anthropometric measurements, Dynamics and Isometric judogi chin-up, CMJ, BDNF, Handgrip	– 5-week cognitive motor training (CMT) using Fitlights

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	(2.) $n=27$	(2.) N.A.		(2.) N.A.		– 5-week judo-specific CMT improved EFs (better accuracy of flanker and digit span) and motor performance in élite judo athletes.
		(3.) N.A.		(3.) N.A.		
				(4.) N.A.		
Kapur and Joshi 2024	(1.) Fastball athletes (handball, volleyball, football and cricket)	(1.) $n=1$	Vienna test system (for attention and concentration)	(1.) Computer		Acute and chronic (4 weeks) effects of different exercise intensity (HIIE and MCE) on cognitive functions
	(2.) $n=20$	(2.) N.A.		(2.) N.A.		– Both HIIE and MCE improvement in attention, inhibitory function as well as executive function (sum of correct reactions, incorrect reactions and incorrect nonreactions).
		(3.) N.A.		(3.) N.A.		
				(4.) Quiet rooms		
Cross-Sectional Studies						

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First author (year)	(1.) Participants' characteristics (2.) Number of participants'	(1.) Number of cognitive tests (2.) Order of cognitive tests (if $n>1$) (3.) Familiarization (Number of trials/accuracy)	Type of cognitive test (Cognitive domain as described in the study^)	Methodological characteristics (1.) Tools or Platform used for cognitive testing. (2.) Screen size (") and characteristics (3.) Distance and position of the screen (4.) Environmental condition	Other measures	Effects of cognitive performance, mental fatigue, and exhaustion time
	(1.) Elite male rugby players	(1.) $n=4$	Groton Maze Learning Task (EF), Detection Task (psychomotor function), Identification Task (vigilance), One Card Learning Task (visual learning and memory)	(1.) CogState		
MacDonald and Minahan 2016	(2.) $n=18$	(2.) In order stated in the next column		(2.) 14"		– ~They hypothesized about the relationship between performance on a computer-based cognitive battery and a player's ability to perform on the field.
		(3.) Two trials of the test battery		(3.) N.A.		
				(4.) 24°C–25°C—55%–60%		
Wang et al. (2016)	(1.) Table tennis players and controls	(1.) $n=1$	Attention Network Test (RT and attention)	(1.) Psychtoolbox		Table tennis players versus control:
	(2.) player $n=31$ control $n=35$	(2.) N.A.		(2.) N.A.	Sports training experience	– Executive network function (RT and accuracy) for table tennis players
		(3.) Until their accuracy reached 80%		(3.) N.A.		– No significant difference in alerting and orientation networks
				(4.) N.A.		

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Chang et al. (2017)	(1.) Elite Endurance Athletes, Controls and Mixed (2.) Athlete $n=20$ Control $n=20$ Mixed $n=20$	(1.) $n=5$	Digit Span Test (working memory), Picture Completion Test (perceptual organization), Stroop Test (perceptual speed and EF), WCST (shifting of EF), Tower of London Task (planning)	(1.) N.A.		Endurance versus control and mixed groups:
		(2.) N.A.		(2.) N.A.	PAR-Q, IPAQ, GXT, T-test, Vertical Jump	– Cardiovascular fitness for endurance group
		(3.) N.A.		(3.) N.A.		– Motor fitness for mixed group
				(4.) N.A.		– No significant difference in cognitive performance
Liao et al. (2017)	(1.) Elite Badminton Players	(1.) $n=1$		(1.) Windows system		Elite badminton players versus control groups:
	(2.) Players $n=42$ controls $n=15$	(2.) N.A.	Stop Signal Task (motor inhibition and RT)	(2.) 14"		– Stop possibility (i.e., the likelihood of stopping a prepotent response) for elite badminton group
		(3.) 32 trials		(3.) 60-cm viewing distance		
				(4.) N.A.		– Positive relationship between levels of competition and stop possibility

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Brevers et al. (2018)	(1.) Professional athletes and nonathletes	(1.) $n=1$	MV. Stop-Signal Task (proactive and reactive inhibition)	(1.) Psychtoolbox		Athletes versus nonathletes groups:
	(2.) Athlete $n=28$ Nonathletes $n=25$	(2.) N.A.		(2.) 15"		– Athletes higher reactive inhibition performance than nonathletes
		(3.) Nine trials for each level		(3.) N.A.		– Athletes higher proactive inhibition than nonathletes
				(4.) Quiet room		– Elite athleticism through a fine-grained analysis of inhibitory control
Coco et al. (2020)	(1.) Male athletes from the Track and Field Team	(1.) $n=3$	Simple RT, Stroop Color Word Test, Trail Making Test (visual search, set-shifting, and cognitive flexibility).	(1.) N.A.	VO_{2max}, Blood Lactate	30-min steady-state test performed at 60% and at 80% of VO2max
	(2.) $n=20$	(2.) N.A.		(2.) N.A.		– 30-min aerobic exercise is not associated with a worsening of EF (RT) if the blood lactate levels stay within the 4 mmol/L thresholds.
		(3.) Participants were familiarized		(3.) N.A.		
				(4.) N.A.		

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Shao et al. (2020)	(1.) Shooting Athletes	(1.) $n=1$	The Flanker Task (RT)	(1.) E-prime		Expert versus novice and control groups:
	(2.) Athletes $n=20$ Controls $n=12$	(2.) N.A.		(2.) 14"		– RT on simple task for control compared to novice in all three ISI conditions
		(3.) N.A.		(3.) N.A.		– RT on simple task for control compared to expert at 300-ms and 400-ms ISIs
				(4.) Quiet and well-lit laboratories		– RT on complex task for control compared to expert and novice at 300-ms and 400-ms ISIs
Vaughan and Edwards 2020	(1.) Athletes and nonathletes according to their expertise (2.) Nonathlete $n=89$, Novice $n=74$, Amateur $n=75$, Elite $n=65$ Super-elite $n=64$	(1.) $n=3$	Intra-Extra Dimensional Set Shift Test (shifting), Stop Signal Task (inhibition), Spatial Working-Memory Test (working memory)	(1.) CANTAB	NEO Five-Factor Inventory	Correlation between EF and personality:
		(2.) N.A.		(2.) 13″ (touchscreen computer)		– Positive relationship between EF (RT on correct trials) and openness and conscientiousness
		(3.) N.A.		(3.) N.A.		– Negative relationship between EF and neuroticism
				(4.) N.A.		– Bi-directional relationship between EF and extroversion

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						– No relationship between EF and agreeableness
Yongtawee et al. 2022	(1.) Only male athletes who have professional experiences of 5 years (Boxers, Shooters, Soccer Players, and Controls) (2.) $n=120$	(1.) $n=6$	Design Fluency Test (inhibitory control, and cognitive flexibility), Flanker Task (inhibition), Trail Making Test (visual perception, working memory), Simple RT (information processing speed), Choice RT, and Mental Rotation Task (spatial ability)	(1.) Visual C# 2015 programming		Boxers versus shooters, soccer players, and control group:
		(2.) Random order		(2.) N.A.		– Simple RT for boxers compared to soccer players and control group
		(3.) Participants had completed enough practice trials		(3.) N.A.		– Choice RT for control group compared to boxers and soccer players
				(4.) N.A.		– Choice RT test accuracy for boxers compared to control group
						– Mental rotation task for boxers compared to shooters and soccer players

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						– Mental rotation task for control group compared to soccer players – Design fluency test for soccer players compared to shooters and control group – Design fluency test for boxers compared to control group – No significant difference in trail making test-part A
Knöllner et al. (2022)	(1.) Male elite soccer players	(1.) $n=4$	Working memory span test, Trail-making test (Cognitive flexibility), Stop-signal task (Inhibitory control), and Multiple-Object Tracking	(1.) CANTAB, NeuroTracker	Visual Tests (Visual clarity, Contrast sensitivity, Near-far quickness, Hand-eye coordination)	Correlation between EF and visual functions:
	(2.) $n=59$	(2.) N.A.		(2.) N.A.		– Positive relationship between selective attention (i.e., operationalized via Multiple-object Tracking) and hand-eye coordination, near-far-quickness, and visual total

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		(3.) Three practice trials		(3.) The participants were asked to lean against the backrest of the chair and sit comfortably ensuring the same screen distance for each subject.		– Positive relationship between working memory and visual clarity right eye, visual clarity both eyes, near-far-quickness, and visual total
				(4.) Quiet and separated room		– Positive relationship between cognitive flexibility and near-far-quickness
						– Positive relationship between EF total and contrast sensitivity, visual clarity right eye, visual clarity both eyes, hand-eye coordination, near-far-quickness, and visual total
Rahimi et al. (2022)	(1.) Soccer athletes (strategic sport), Track & Field athletes (static sport)	(1.) $n=1$	Attention Network Test-Interaction (alerting, orienting, and executive control)	(1.) Computer.		Soccer athletes versus track & field athletes:
	(2.) $n=97$	(2.) N.A.		(2.) N.A.		– Alerting- no tone, orienting- valid cue, executive- incongruent flanker, overall rt., for soccer athletes
		(3.) 25 practice trials		(3.) N.A.		– Accuracy percentage for soccer athletes

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				(4.) N.A.		
Mancı et al. (2023)	(1.) Basketball players and controls	(1.) $n = 3$ (2.) Randomized order (3.) Three practice trials	Change Detection Test (visuospatial attention and short-term memory), Timewall Test (visuospatial perception and time perception), Mackworth Clock Test (sustained attention and vigilance)	(1.) PEBL (2.) 17" (3.) 70 cm away from the screen (4.) Quiet and well-lit room		Comparison between basketball positions and with control group:
	(2.) Players $n = 37$ Controls $n = 20$					– Trained basketball players superior cognitive capabilities (RT and accuracy) as compared to sedentary controls – Trained basketball players position-related differences in specific cognitive capabilities occur
Paul et al. (2024)	(1.) University students' different branches (Cricket, Volleyball, Kho-Kho, and Kabaddi) and control group (2.) Athletes $n = 100$ Controls $n = 24$	(1.) $n = 2$	Tower of London Test (planning and problem-solving ability) and Stroop Color and Word Test (attention, processing speed, cognitive flexibility and working memory)	(1.) Computer.		Comparison between Cricket, Volleyball, Kho-Kho, and Kabaddi branches and with control group

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		(2.) N.A.		(2.) N.A.		– Team sports athletes have higher inhibitory control, self-control and cognitive flexibility compared to the control group
		(3.) N.A.		(3.) N.A.		
				(4.) N.A.		

Abbreviations: ^, Test statements are based on the reference studies; BDNF, Brain-derived neurotrophic factor; BRUMS, Brunel mood scale; CMJ, Counter movement jump; CMT, Cognitive motor training; EF, Executive function; ESS, Epworth sleepiness scale; GPS, Global positioning system; GXT, Graded exercise test; HIIE, High-intensity interval exercise; HR, Heart rate; IPAQ, International physical activity questionnaire; ISI, Interstimulus interval; MCE, Moderate intensity continuous exercise; MoCA, Montreal cognitive assessment; MV, Modified version; N.A., Not applicable; PARQ, Physical activity readiness questionnaire; PDQ, Perceived deficits questionnaire; PEBL, Psychology experiment building language; POMS, Profile of mood states; PSS, Perceived stress scale; PVT, Psychomotor vigilance task; RER, Respiratory exchange rate; RPE, Rating of perceived exertion; RT, Reaction time; SART, Sustained attention to respond task; TaW, Taper week; TMD, Total mood disturbance; TrW, Training week; VAS, Visual analogue scale; $VO2_{max}$, Maximal oxygen uptake; WCST, Wisconsin card sorting test.

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TABLE 2 | Preferred reporting items for cognitive factors assessing studies checklist for completed studies.

Topic	Item #	Checklist Item	Locations (NA: not applicable)
Cognitive Tests			
Test selection	1a	Report the used cognitive tests and the reasons.	
	1b	Explain the theoretical and/or practical background between the cognitive test and the sportive performance in detail.	
Implementation of Cognitive Tests			
Differences in assessment tools/platforms	2a	Report the application/tools the cognitive tests were performed.	
	2b	Report the validity and reliability of the cognitive tests and tools (cited).	
The order of administration and familiarization of cognitive tests	3a	Report if a familiarization session was performed. If so, explain in details (when, how many repetitions, in what order).	
	3b	Consider and report the learning effect.	
	3c	Report the number of cognitive tests were performed, in which order they were administered, if the mental load considered when several cognitive tests have been applied.	
Differences in technical features and testing environment	4a	Report the information about the hardware (e.g., GPU, CPU, RAM, etc.) on which the cognitive tests were performed.	
	4b	Report the information about the peripheral components of the computer (Mouse DPI, Screen Frame, or FPS) on which the cognitive tests were performed.	
	4c	Report the screen size.	
Environmental and other factors that can affect cognitive test results			
Time of the day/chronotype	5a	Report the time (e.g., morning, noon, and afternoon) at which the cognitive tests have been administrated.	
Environmental conditions	5b	Report the environmental conditions (e.g., temperature, humidity, and lighting) in which the cognitive tests were administered.	
Participant characteristics			
General characteristics	6	Report the participant and group characteristics (e.g., age, sex, BMI, athlete status, sports discipline).	
Mental fatigue status	7	Determine and report the participants' mental fatigue status before the cognitive tests.	
Nutritional status	8	Determine and report the participants' nutritional status before the cognitive tests.	
Eye health status	9	Determine and report the participants' eye health status by objective tests.	

studies, tools such as COMPASS (Costello et al. 2023) and CogState (MacDonald and Minahan 2016) have been utilized. Some of these assessment tools can be freely used (e.g., psychology experiment building language—PEBL, PsychoPy, and Psychtoolbox), while some of those require a license (e.g., E-Prime, CANTAB, CogState, COMPASS, Neuroscan System).

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TABLE 3 | Contradictions/limitations of the studies and recommendations table for researchers.

Limitations of the studies	Recommendations[a]
Considering the literature reviewed, most of the studies focused on reaction time and inhibition, but sportive skills comprise a wide range of cognitive components.	Since sports and exercise are a complex field of research, not an only investigation of cognitive abilities such as reaction time, inhibition, and memory, but also cognitive processes of visual perception, timing, risk-taking, decision may contribute to a deeper understanding of the relationship between cognitive performance and sports.
Variations in cognitive performance that arise from the modification of standardized cognitive tests lack of data this modification procedures.	Using cognitive tests with sound psychometric properties (e.g., validity and reliability) and/or providing more detailed information about the administration and modification of cognitive tests in the studies may assist in the appropriate standardization of the methodology of future research.
Variations in cognitive performance that may arise from hardware differences (pen-and-pencil-based vs. computer-based, 9-in. screen to 21-in. screen), or software differences (e.g., different operating systems and software platforms) by which cognitive tests are applied.	It has been reported that larger screens allow more information to be visualized simultaneously, alleviating cognitive load, and in particular faster response times (Hancock et al., 2015; Czerwinski et al. 2003). Therefore, it may be advisable[b] to report screen size and use larger screen sizes in studies.
Variations of cognitive performance that arise from differences in the testing environment (e.g., room temperature, room brightness, and distances from the screen (100 cm, 70 cm, 50 cm).	Among the studies analyzed in this systematic review, the most frequently used distance to the screen in adults was ~70 cm. Based on the wide range of parameters in the studies, it is not possible to provide more nuanced recommendations on screen size and ambient light conditions.
Variations of cognitive performance that areise from cognitive tests conducted at different times of day (morning or noon)	As circadian rhythm is associated with cognitive performance (Schmidt et al., 2007), of cognitive tests it is recommended to report the time of day.
Variations in cognitive performance that arise from differences use of multiple cognitive test and test order.	Whether the tests have a learning effect, the order in which they are administered and whether they cause cognitive load should be checked and reported.
Variations in cognitive performance that arise from differences in the familiarization procedures.	Participants must repeat the cognitive tests a sufficient number[c] of times before actual cognitive performance is investigated. However, the learning effect and cognitive load in multiple testing studies should not be underestimated.
Nutritional levels and feelings of hunger and satiety of the participants before the cognitive test may affect cognitive performance. Ignoring these factors may lead to a misleading conclusion that the positive/negative effect on cognitive performance is caused by exercise.	As nutritional status is associated with cognitive performance, the nutritional status of the participants should be checked and reported as suggested by Goulart et al. 2023; Karpecka and Facxek., 2020.

[a]These recommendations should be validated with further studies.
[b]The effect of computer screen size on cognitive performance has not been conclusively established.Therefore, further research is needed.
[c]As seen from the literature review, there is a need for further studies on familiarization sessions before cognitive performance measurement.

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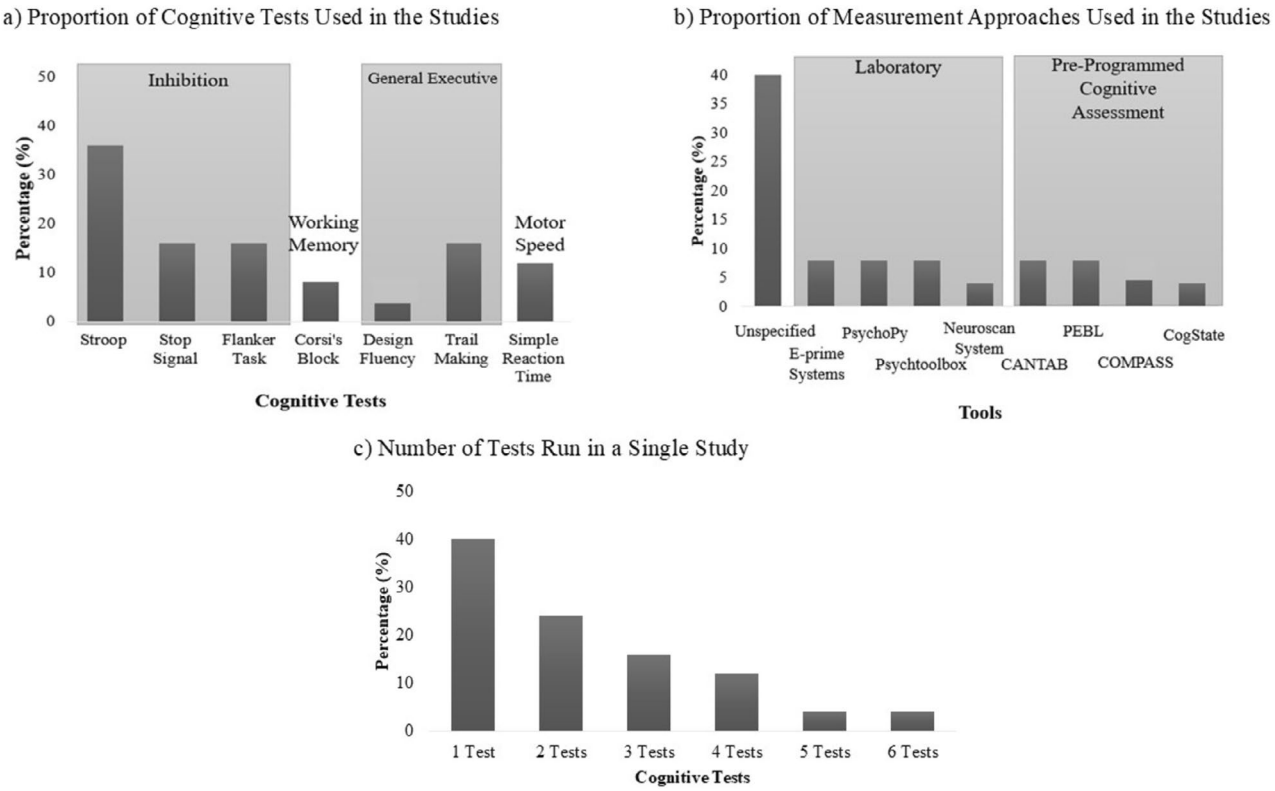


FIGURE 2 | (a) Illustration of the proportion of cognitive tests used in each of the studies. Tasks that assess similar components of cognition are grouped (b) Illustration of the proportion of measurement approaches used in the studies. Preprogrammed cognitive assessment tools are distinguished from those tools that are laboratory-grade approaches that enable custom task parameters (c) Illustration of the number of cognitive tests run in each single study.

Both tablet/phone-based (González-Fernández et al. 2024; Knöllner et al. 2022) and computer-based (Brevers et al. 2018; Chang et al. 2014; Shields et al. 2017; Yongtawee et al. 2022) tools were employed. One study administered paper-based testing (Kuroda et al. 2023). Besides these, during the literature review, it was observed that the freely available PEBL test battery (Mueller and Piper 2014; Piper et al. 2012, 2015) is also used in some studies (Gutiérrez-Capote et al. 2024; Gümüş et al. 2020; Manci et al., 2023; Mancı et al. 2021).

3.3 | Familiarization of Cognitive Tests

There is considerable heterogeneity concerning the familiarization with procedures of cognitive testing. For instance, the familiarization with cognitive test procedures was not addressed, or the familiarization was not clearly explained in twelve studies (Azevedo and Carpes 2021; Chang et al. 2017; Costello et al. 2023; González-Fernández et al. 2024; Campanella et al. 2024; Kapur and Joshi 2024; Kuroda et al. 2023; Lopes et al. 2020; Paul et al. 2024; Rincón-Campos et al. 2019; Shao et al. 2020; Vaughan and Edwards 2020). On the other hand, in some studies, 25 familiarization trials were conducted (Shields et al. 2017; Rahimi et al. 2022), while only 2 test trials of the stimulus were performed in one study (MacDonald and Minahan 2016). In two studies, it was stated that the test trials were conducted until a plateau in the performance was reached (i.e., no significant increase despite practice), the number of errors was minimized, a certain percentage of accuracy was achieved, or the participant felt confident and asked to terminate practicing (Chang et al. 2014; Wang et al. 2016).

3.4 | Application Configuration and Testing Environment

Our analysis of the 25 studies showed that 17 studies did not specify how and under which conditions the tests were applied (e.g., Campanella et al. 2024; Chang et al. 2017, 2014; Kapur and Joshi 2024; Liao et al. 2017; Paul et al. 2024; Rahimi et al. 2022; Shields et al. 2017; Wang et al. 2016). In studies reporting the screen sizes used, sizes ranged from 4 in. (by phone; González-Fernández et al. 2024), 13 in. (Vaughan and Edwards 2020), to 21 in. (Chang et al. 2014). The number of studies reporting the conditions of the testing environment is limited because only a few studies describe the conditions in which the cognitive testing was conducted as follows: in a quiet environment (Brevers et al. 2018; González-Fernández et al. 2024; Gutiérrez-Capote et al. 2024; Kapur and Joshi 2024) or a quiet and well-lit room (Shao et al. 2020; Rincon-Campos et al., 2019; Manci et al., 2023). In one study, the ambient temperature varies between 22°C (González-Fernández et al. 2024), 24°C and 25°C (MacDonald and Minahan 2016), and in another 10.3°C (Malcolm et al. 2022). In the remaining studies, no information on temperature was found. Another important parameter concerning cognitive testing is the distance between the participant and the screen. Only five studies included in this systematic review have properly

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reported the distance between the participants and the screen (i.e., 60 cm or 100 cm distance from the screen) (Azevedo and Carpes 2021; González-Fernández et al. 2024; Gutiérrez-Capote et al. 2024; Manci et al., 2023; Liao et al. 2017). Another prominent issue regarding the application of cognitive tests is the number of trials and the interstimulus interval, which were not appropriately reported in almost all the included studies. Besides, only three studies included in the review provided information about the participants' visual impairment (Knöllner et al. 2022; Shao et al. 2020; Wang et al. 2016), and the other studies did not make any statements in this regard.

4 | Discussion

This systematic review focused on the methodology/methods of applied cognitive tests aimed: (i) to summarize and analyze which cognitive tests are used to test cognitive performance in (amateur/elite) athletes and (ii) to derive—based on the analysis of the literature recommendations—for future studies. In the following sections, we will discuss the findings of our systematic review focused on the methodology of applied cognitive tests in more detail.

4.1 | Cognitive Tests

There are three core executive functions (EFs): inhibition, working memory, and cognitive flexibility. Higher-level EFs are formed by reasoning, problem-solving, and planning. Our results showed that most of the reviewed studies focused on the assessment of executive functions by utilizing either the Stroop test (Chang et al. 2014; Coco et al. 2020; Costello et al. 2023; Lopes et al. 2020; Malcolm et al. 2022; Rincón-Campos et al. 2019; Shields et al. 2017) or the Trail Making Test (Coco et al. 2020; Knöllner et al. 2022; Rincón-Campos et al. 2019; Yongtawee et al. 2022); (Figure 2a). Thus, it seems a promising area for future studies to investigate executive functions associated with sportive performance. Such research may also seek to extend our knowledge to other cognitive domains, such as anticipation, which is important for many sports disciplines (e.g., to predict the opponent's movement attempt) (Loffing and Cañal-Bruland 2017) and which can be assessed in a laboratory setting via the "non-sport specific" Anticipation/Coincident Timing Test. Carrying out such research on the associations between general cognitive abilities measured in a laboratory setting (also referred to as the "cognitive component approach") (Scharfen and Memmert 2019; Voss et al. 2010) can complement research in an ecologically valid setting (i.e., sport-specific context, also referred to as "expert performance approach") (Mann et al. 2007; Scharfen and Memmert 2019) to advance our understanding of the role of cognitive functioning in high-level sports performance. In this context, examining the relationship between these laboratory-based cognitive tests and game performances (e.g., match statistics) within a perspective of sport-specific/general cognitive test selection is an important area for future investigations.

Given that in the reviewed studies, the rationale and specific parameters of the cognitive test were often not appropriately specified (e.g., interstimulus interval: ISI), further studies should consider addressing this shortcoming by providing a more detailed description of these important methodological factors.

That methodological details such as the interstimulus interval can be a serious confounder is, for instance, documented by several studies on inhibition performance (Galer et al. 2014; Nakata et al. 2005; Ryan et al. 2010; Wodka et al. 2009). For example, a study on the Stroop test in children and younger adults, which is a frequently used test in the field of exercise-cognition science (e.g., ten of the reviewed studies used the Stroop test), evinced that the interference effects in the Stroop test become more pronounced for short interstimulus intervals compared to longer ones (i.e., 1000 ms. vs. 3000 ms.) (Galer et al. 2014). Although there is, at least to the best of our knowledge, no study available that investigated this phenomenon in athletes, it seems reasonable to assume that reporting such important methodological details is imperative to better explain potential sources of heterogeneity in studies using the cognitive component skill approach in athletes.

4.2 | Implementation of Cognitive Tests

4.2.1 | Differences in Assessment Tools/Platforms

The cognitive performance tests in the reviewed studies were administered through a wide range of test batteries/programs using either paper-and-pencil testing (Elferink-Gemser et al. 2018; Niedermeier et al. 2020; Van den Berg et al. 2016) or computer-based solutions, including the utilization of E-Prime (Shields et al. 2017) or Cogsate (MacDonald and Minahan 2016).

There is evidence in the literature that in the general population, pencil-based and computer-based tests can differ in terms of performance measures (Bracken et al. 2019; Clariana and Wallace 2002; Penner et al. 2012), although a high correlation between the two modes of testing was observed in other studies (Latendorf et al. 2021; Park and Schott 2022). Based on the fact that results obtained in the general population might not be fully generalizable to the population of athletes, some caution should be applied when comparing the results of pencil-based and computer-based cognitive tests, and further research in this direction is needed before more solid conclusions can be drawn. Conducting cognitive tests via different software platforms may introduce some bias in specific measures of cognitive performance (e.g., reaction time). In this context, Bridges et al. (2020) examined the sensitivity and accuracy of visual and auditory stimulus timing and reaction times on different platforms and operating systems (i.e., Windows, macOS, and Ubuntu) such as PsychoPy, E-Prime, NBS Presentation, Psychophysics Toolbox, OpenSesame, Experiment, Gorilla, jsPsych, Lab.js, and Testable (Bridges et al. 2020). For example, Bridges et al. (2020) reported that Psychtoolbox, PsychoPy, Presentation, and E-Prime were more sensitive (under 1 millisecond) than the other applications (e.g., regarding visual, audio, and response measures). That macOS was inferior in providing visual stimuli compared to the other operating systems (e.g., Windows) (Bridges et al. 2020). In addition, Python code in PsychoPy or every equivalent for the other programs should be uploaded to GitHub or a scientific repository Open Science Framework (OSF) so that tests can be

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reused/repeated/reproduced. That would help to standardize the application of cognitive tests. Given that the aforementioned study provided evidence that operating systems and software platforms are crucial factors for cognitive testing, future studies in this direction (e.g., in athletes) are needed to improve our understanding of potential differences between operating systems and software platforms so that a more robust study design can be established.

Additionally, some modified versions of cognitive tests are used (Brevers et al. 2018; Kuroda et al. 2023). From a general point of view, we recommend that when a modified version of a cognitive test is used, this should be clearly stated to allow for a better comparison across studies. To foster standardized reporting and the reproducibility of the study procedures, we recommend that the software platform used for cognitive testing be appropriately specified in the method section of the study.

4.2.2 | Differences in Technical Features and Testing Environment

The distance to the screen was not clearly reported in almost all the studies analyzed in this review. The typical screen distance for cognitive testing in adults is around 70 cm (e.g., Brush et al. 2016; Chang et al. 2019; Chiu et al. 2020), while other screen distances, such as 100 cm in adults (Drollette et al. 2014; Shibasaki et al. 2019) or 50 cm in children, have been reported (Ishihara et al. 2017).

Our literature review shows that screen sizes varied considerably between studies from 4 to 21 in., while the frequently used size was 14 in. (Chang et al. 2014; González-Fernández et al. 2024; Shao et al. 2020). Previous studies have demonstrated a positive effect of larger screen sizes and greater resolutions on cognitive performance, such as memory performance (Czerwinski et al. 2003; Ni et al. 2006; Tan et al. 2006). However, the literature has no consensus on the optimal screen size for cognitive testing. Thus, to improve comparability across studies, we suggest that future studies should report the distance to the screen as well as important technical information (e.g., screen size and visual angle).

4.2.3 | The Order of Administration and Familiarization of Cognitive Tests

We noticed that most of the reviewed studies did not report the use of familiarization trials (Azevedo and Carpes 2021; Costello et al. 2023; Lopes et al. 2020; Rincón-Campos et al. 2019; Shao et al. 2020; Vaughan and Edwards 2020). However, even studies applying familiarization trials showed a considerable variation in terms of their administration (Alves et al. 2014; Chrismas et al. 2019; Edwards and Loprinzi 2018). For example, Shields et al. (2017) reported that they allowed their participants to perform 25 familiarization trials, while MacDonald and Minahan (2016) reported that they offered their participants only two familiarization trials. In the other studies, the familiarization was performed until the participant achieved a specific level of accuracy (Chang et al. 2014; Wang et al. 2016). In addition, while some studies organized a familiarization day (MacDonald and Minahan 2016; Malcolm et al. 2022), others conducted the familiarization on the same day as the assessments (Shields et al. 2017). Given that learning effects can bias the performance in cognitive testing without appropriate familiarization, our findings support the notion that there is a need to standardize further the procedures used to familiarize participants with cognitive testing in exercise-cognition science (McMorris 2016). Thus, we propose that (a) further efforts should be undertaken to achieve and establish a consensus on objective procedures of familiarization, and (b) due to the absence of such consensus, researchers should report their familiarization procedures in as much detail as possible (e.g., How many trials have been performed? Which level of accuracy was deemed appropriate before the cognitive testing was conducted?).

In addition, when various cognitive tests have been applied for a long time as a test battery (e.g., Stroop, N-back, Flanker), effects related to cognitive load and cognitive fatigue may occur. For instance, the performance in the first test (i.e., Stroop test) and the third (i.e., N-back test) or fifth test (i.e., Flanker test) may differ in parallel to the increase in mental load/fatigue of the participant (Gebel et al. 2022). Eliminating all confounders is often not possible due to the time-consuming nature of cognitive tests. However, a potential strategy to minimize such bias in studies using several cognitive tests is (i) the randomization of the order of the cognitive tests or (ii) examining the specific cognitive ability in isolation (i.e., using a single cognitive test) rather than a cognitive test battery, although such decisions on methodological procedures are context-dependent (i.e., considering the study design and research aims). Studying cognitive abilities in isolation (i.e., via a single cognitive test) is also motivated by the assumption that applying several cognitive tests in a row presents a potential bias against observing subtle differences in cognitive performance (e.g., athletes vs. nonathletes) due to the increased likelihood that the participant's cognitive performance will approach some practice-related limits (Calamia et al. 2012; Pontifex et al. 2019).

4.2.4 | Environmental and Other Factors That Can Affect the Results of Cognitive Testing

In general, there is solid evidence in the literature that factors such as (a) time of day/chronotype (Facer-Childs et al. 2018; Schmit et al. 2015), (b) nutritional status (Goulart et al. 2023; Karpecka and Fraczek 2020), environmental conditions (Martin et al. 2019; Taylor et al. 2016), vision health (Nitzan et al. 2024; Wood et al. 2009) can influence cognitive performance. Concerning the reviewed studies, those factors were only partly reported (Azevedo and Carpes 2021; Brevers et al. 2018; Knöllner et al. 2022; MacDonald and Minahan 2016; Malcolm et al. 2022; Rincón-Campos et al. 2019; Shao et al. 2020) or not appropriately considered (e.g., it has not been reported whether study procedures were standardized to account for the factors). To minimize such factors' influence, a high level of standardization is necessary. However, a consensus on how to standardize experimental procedures is lacking and remains to be established for the field of exercise–cognition science. As a first step, considering these factors and reporting them in as much detail as possible will likely increase the quality and comparability of the studies.

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Given (i) that vision is a crucial factor for a wide range of frequently used cognitive tests in the field of exercise-cognition science (e.g., Stroop test) and (ii) that visual impairment is closely related to cognitive performance (Knöllner et al. 2022; Wood et al. 2009), controlling for visual impairments (e.g., via objective and validated screening tools) should be mandatory when aiming to provide reliable results. However, in most reviewed studies, it was not objectively controlled for visual impairment (Costello et al. 2023; Malcolm et al. 2022; Manci et al., 2023). To address this issue, future studies, especially studies with a between-subjects design, should consider using freely available screening tools such as the NIH Toolbox or the Freiburg Vision Test (FrACT) to objectively control for visual impairments (Bach 1995; Farassat et al. 2024).

Reporting as much as possible from this list will both increase the methodological quality of the studies and facilitate the identification of methodological differences when compared with other studies.

Limitation.

This study's focus on recent years to review recent publications can be considered a limitation. In addition, although cognitive performance appeals to a very wide population, only focusing on athletes in this review can be another limitation. In future studies, we believe that more detailed information can be obtained if this methodological approach is included in studies involving larger populations.

5 | Conclusions

The findings of this systematic review focused on the methodology of applied cognitive tests and observed considerable heterogeneity in methodological procedures applied in studies investigating the cognitive performance of athletes. To enhance the rigor and comparability of future studies, we propose (i) investigations into the potential impact of methodological differences on the evaluation of cognitive performance in athletes and (ii) a more comprehensive and transparent documentation of methodological procedures. To this end, we have formulated a checklist to enhance the quality of forthcoming investigations and facilitate more transparent reporting. Consequently, we hope that this systematic review, which aims to derive methodological recommendations by summarizing the current state of the literature on cognitive testing in athletes, is the first step to improving the quality of further studies in the field investigating cognitive functions in athletes.

Author Contributions

Egemen Manci: conceptualization, methodology, software, resources, data curation, writing – original draft, writing – reviewing and editing, visualization, project administration. Fabian Herold: writing – reviewing and editing, visualization, supervision. Firat Özdalyan: methodology, software, resources, data curation, writing – original draft, writing – reviewing and editing. Merve Demir Benli: original draft, writing – reviewing and editing. Çağlar Bozkurt: resources, data curation, writing – original draft. Uğur Gençtürk: writing, data curation. Arnd Gebel: writing – reviewing and editing. Çağdaş Güdücü: methodology, software, writing – original draft, writing – reviewing and editing. Erkan Günay: methodology, writing – original draft, writing – reviewing and editing. Cem Ş. Bediz: reviewing and editing, supervision. Matthew B. Pontifex: visualization, reviewing and editing, supervision. Notger Muller: reviewing and editing, supervision *All authors have read and approved the final version.

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During the preparation of this work, the authors used Grammarly and ChatGPT4.0 to improve the readability and language. After using this tool/service, the authors reviewed and edited the content as needed and took full responsibility for the publication's content.

Disclosure

The current study is registered with the Open Science Framework (https://doi.org/10.17605/OSF.IO/DC29X).

Ethics Statement

The authors have nothing to report.

Consent

The authors have nothing to report.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The authors have nothing to report.

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