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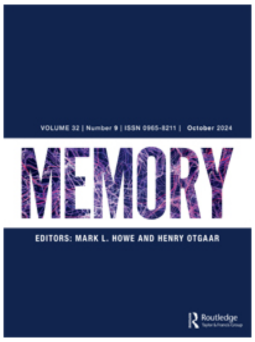
ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/pmem20



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To cite this article: Chenxiao Wu, Chenyuan Zhang, Xueqiao Li, Chaoxiong Ye & Piia Astikainen (06 Nov 2024): Comparison of working memory performance in athletes and non-athletes: a meta-analysis of behavioural studies, Memory, DOI: 10.1080/09658211.2024.2423812

To link to this article: https://doi.org/10.1080/09658211.2024.2423812

Published online: 06 Nov 2024.

MEMORY
https://doi.org/10.1080/09658211.2024.2423812

REVIEW ARTICLE

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Comparison of working memory performance in athletes and non-athletes: a meta-analysis of behavioural studies

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ABSTRACT
The relationship between sports expertise and working memory (WM) has garnered increasing attention in experimental research. However, no meta-analysis has compared WM performance between athletes and non-athletes. This study addresses this gap by comparing WM performance between these groups and investigating potential moderators. A comprehensive literature search identified 21 studies involving 1455 participants from seven databases, including PubMed, Embase, and ProQuest. Athletes primarily engaged in basketball, football, and fencing, while non-athletes included some identified as sedentary. The risk of bias assessment indicated low risk across most domains. Publication bias, assessed through a funnel plot and statistical tests, showed no significant evidence of bias. The forest plot, using a random effects model, revealed moderate heterogeneity. The overall effect size indicated a statistically significant, albeit small, advantage for athletes over non-athletes (Hedges' g = 0.30), persisting across sports types and performance levels. Notably, this advantage was more pronounced when athletes were contrasted with a sedentary population (Hedges' g = 0.63), compared to the analysis where the sedentary population was excluded from the non-athlete reference group (Hedges' g = 0.15). Our findings indicate a consistent link between sports expertise and improved WM performance, while sedentary lifestyles appear to be associated with WM disadvantages.

ARTICLE HISTORY
Received 24 June 2024
Accepted 21 October 2024

KEYWORDS
Athletes; working memory; sports; cognition; sedentary lifestyle

Introduction

Sports and cognition

High-level sports performance relies on athletes' physiological and technical skills, as well as the development and application of cognitive functions (Fang et al., 2022; Scharfen & Memmert, 2019). The link between sports and cognition is further manifested in the continuous cognitive engagement and the challenges encountered during the development of sports expertise (Yarrow et al., 2009), which also leads to plastic changes in the brain (Roberta et al., 2020). Evidence at the brain level indicates that exercise enhances cognitive functions through mechanisms such as angiogenesis, synaptogenesis, and neurogenesis, which are essential for maintaining and improving neuroplasticity (Hillman et al., 2008). In contrast, sedentary lifestyles have been associated with reduced cognitive performance (Falck et al., 2017), and this adverse effect even involves gene expression and inheritance (Di Liegro et al., 2019). It appears that reducing sedentary behaviours and incorporating regular exercise are crucial strategies for optimising cognitive health.

WM and its role in sports

Recent research has suggested that attention, perception, and decision-making are increasingly being incorporated into the field of sports and exercise psychology (Kalén et al., 2021), with a particular emphasis on the importance of working memory (WM) (Furley & Memmert, 2010b). WM refers to the ability to mentally retain and manipulate information, acting as a short-term storage system with limited capacity (Baddeley, 2012). In behavioural research, WM is typically assessed using tasks that measure both storage and processing of information. For example, the N-back task assesses updating and maintaining information by asking participants to identify whether the current stimulus matches one from n trials earlier. The digit span task measures recall of number sequences forwards or backwards, reflecting information maintenance and manipulation. The delayed match-to-sample task

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Supplemental data for this article can be accessed online at https://doi.org/10.1080/09658211.2024.2423812.

tests retention and retrieval by requiring participants to match a test stimulus with a viewed sample after a brief delay.

Extensive research has explored the mechanisms of WM, revealing its adaptive and dynamic nature rather than a fixed construct (Li et al., 2020; Liu et al., 2022; Ye et al., 2017, 2020, 2024; Zhang et al., 2022). Findings suggest that WM resources can be reallocated to specific representations during maintenance, reflecting the system's flexibility (Liu et al., 2023; Souza et al., 2014, 2015, 2016; Ye et al., 2016, 2021). These experimental findings provide a basis for understanding WM's role, which extend to its specific applications in sports (Furley & Wood, 2016; Glavaš et al., 2023). WM, particularly its capacity, plays a crucial role in the efficiency and quality of cognitive processing required for athletes to access information when executing tactics. For example, football players rely on WM to monitor the positions of teammates and opponents during games, facilitating quick and strategic passing decisions (Vestberg et al., 2012).

Although athletes have displayed advantages in sports-specific WM tasks (Heilmann, 2021), this does not necessarily imply superiority in non-sports-specific, general WM tasks. The former refers to tasks where the content is directly related to sports, such as recalling player positions or game tactics, while the latter involves broader cognitive challenges, like remembering numerical sequences or verbal information, which do not pertain to the sporting context. Investigations on non-sports-specific cognition have shown contradictory results. Some studies have indicated that athletes are better than non-athletes at general WM tasks, suggesting that sports expertise may have a broad, positive link to cognitive function (Manci et al., 2023; Wang et al., 2023), while other studies have found no significant superiority in general WM attributable to sports expertise (Khoroshukha et al., 2023; Nian et al., 2023; Song et al., 2024). Additionally, sports type appears to influence athletes' WM (Gokce et al., 2021).

Impact of sports expertise on cognitive functions

One potential explanation for the impact of sports expertise on WM is the transfer hypothesis, which has been proposed as a general mechanism for explaining the effects of sports expertise on cognitive function (Logan et al., 2023), ranging from sports-specific tasks to general cognitive tasks. The narrow transfer hypothesis argues that individuals with abundant experience in their area of expertise exhibit an edge in cognitive processing, attributable to their utilisation of long-term memory in processing domain-specific information (Guida & Tardieu, 2005; Zoudji et al., 2010). However, this advantage does not seem to be transferable to general tasks due to the lack of activating expertise-related cues (Heilmann, 2021). In line with this, studies have found that athletes exhibit enhanced efficiency in sports-related cognitive tasks, but this advantage does not extend to general cognitive tasks (Fang et al., 2022). The broad transfer hypothesis contends that long-term engagement in a particular activity fosters improvement in a wider range of cognitive functions that goes beyond the domain of expertise (Furley & Memmert, 2011).

Existing meta-analyses investigating the effect of sports expertise on cognitive functions have revealed that athletes outperform non-athletes in processing speed and attention tasks (Voss et al., 2010), and in attentional allocation and cognitive flexibility (Logan et al., 2023), but WM was not examined in these studies. Another study noted an advantage in general cognitive function among athletes (Kalén et al., 2021); however, their study lacked detailed subdivision of cognitive functions and a thorough analysis of moderators, such as sports type and performance level. In studies comparing the executive functions in open – versus closed-skilled athletes, no significant differences in WM were observed between the two athlete groups, although open-skilled sports are suggested to place higher demands on cognition (Heilmann et al., 2022). This finding provides preliminary support for the narrow transfer hypothesis, but also points to an important gap in the study, namely the absence of a non-athlete reference group in these comparisons, which limits the insights into the broader impact of sport expertise on WM. Overall, the impact of sports expertise on WM remains inconclusive.

Inconsistent findings in WM comparisons between athletes and non-athletes

Cross-sectional studies have shown inconsistent findings concerning the comparison of WM performance between athletes and non-athletes. Supporting the narrow transfer hypothesis, Heilmann (2021) indicated that climbers excel in WM tasks related to their expertise, whereas they did not exhibit the same edge in general WM performance. Likewise, Seo et al. (2012) revealed that archery experts had no advantage in general WM tasks. By comparison, Zoudji et al. (2010) were unable to confirm any superior performance in non-football-related memory tasks among world-class players, whereas Wang et al. (2023) provided evidence suggesting broader cognitive benefits, showing that football players outperformed non-athletes in both expertise-related and general WM tasks. Another study involving fencers, swimmers, and sedentary individuals emphasised how different sports may uniquely enhance WM and attributed this to the intricate motor execution required by fencing and its interaction with cognitive processing (Gokce et al., 2021).

These inconsistent results could partially reflect limitations due to sample size. Small samples often yield inconclusive results, not due to a lack of effect, but insufficient statistical power to detect it (Schmidt, 1992). To identify stable effects that may otherwise remain undetected in studies with small sample sizes, meta-analysis serves as an apt channel for synthesising findings. Furthermore, since the assessment of general WM is subject to the influence of various moderators, such as age, sports type, and sports performance level, these create challenges when attempting to ensure homogeneity and comparability across research outcomes. Therefore, this study conducted a meta-analysis of the existing literature to enable a critical assessment of WM performance in athletes versus non-athletes.

One point to note is that this study distinguishes athletes from the physically active population, because athletes typically have a higher level of training and performance compared to physically active non-athletes (McKay et al., 2022). Moreover, a recent study has elucidated the benefits of physical activity on WM in children and older adults (Zhu et al., 2023).

Hypotheses on WM in athletes vs. non-athletes

Given the extensive studies indicating a positive link between sports expertise and cognitive function, the present meta-analysis posits a core hypothesis: Athletes outperform non-athletes in non-sports-specific WM tasks investigated through behavioural experiments. The performance differences in these studies would suggest a broad transfer effect, indicating that the advantages observed in athletes extend beyond sports-specific tasks to general cognitive tasks. To explore this hypothesis, the present study was designed to investigate a range of moderators that might influence the relationship between sports expertise and WM. These include age, sports type (team vs. individual; open-skilled vs. closed-skilled; aerobic vs. anaerobic; high-collision vs. low-collision), sports performance level (elite vs. non-elite), and physical activity of the reference group. Specifically, the expectation is that older athletes will exhibit a greater advantage in WM relative to other age groups due to the anti-aging benefits provided by consistent engagement in sports (Tanaka et al., 2011). For team sports, a more significant WM advantage is anticipated because these athletes need to dynamically process substantial interactive information (Andersen et al., 2019). Given the high demands placed on executive function in open-skilled sports (Zhu et al., 2020), we also expect that athletes participating in these sports will display a more marked advantage in WM in comparison to closed-skilled athletes. Additionally, aerobic sports are predicted to show a stronger positive link with WM through biological mechanisms, which supports improved brain health (Stern et al., 2019). Given the potential risks associated with brain injuries in high-collision sports (Slobounov et al., 2017), athletes participating in low-collision sports may exhibit superior performance in WM tasks. Elite athletes are expected to perform better in WM tasks than non-elite athletes when non-athletes are the reference group, due to their extensive experience and optimised attention allocation during training and competition (Moran, 2008). Finally, given the detrimental impact of prolonged sedentary lifestyles on cognitive function (Falck et al., 2017), it is expected that athletes will have a clearer WM advantage over the sedentary population than over the non-athlete reference group that excludes sedentary individuals.

Materials and methods

Protocol

This study adheres to the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) 2020 statement (Page et al., 2021). The protocol was registered in PROSPERO (CRD42024506333) and INPLASY (INPLASY202420066). The methods and criteria for inclusion and exclusion were clearly described in the registered protocol. For detailed information, the full protocol is publicly available at https://osf.io/sgwp2/.

Literature search strategy

A comprehensive retrieval of literature related to the topic was achieved using a search plan encompassing seven electronic databases: PubMed, Web of Science, MEDLINE (Ovid), APA PsycInfo/PsycArticles, Scopus, ProQuest, and Embase. The literature search was extended up to January 29, 2024, with no restrictions imposed on publication date or language. The search strategy consists of two parts: "Athletes" and "Working memory". "Athletes" and its associated entry terms, including "Players" and "Player", were first identified using Medical Subject Headings (MeSH). "Working memory" along with its relevant entry terms, were then searched via MeSH. The Boolean logical operator "OR" was used to combine words within the same concept, while "AND" was utilised to merge the two concepts. In addition, to minimise the omission of pertinent literature, relevant reviews and their references were manually examined. Details of the search strategies are documented in the supplementary material.

Eligibility criteria

To ensure the validity and accuracy of this meta-analysis, a set of inclusion and exclusion criteria was established for strict screening of the literature suitable for review. The inclusion criteria for the studies are: 1. Original (empirical) studies; 2. Cross-sectional studies; 3. Assessment of WM using a behavioural measure (e.g., accuracy, capacity); 4. Healthy participants; 5. Both athlete and non-athlete populations investigated. Athletes are those who participate in competitive sports and meet Tier 2 criteria or above (i.e., those who identify with a specific sport and train for the purpose of competition) (McKay et al., 2022). Non-athletes are those who meet Tier 0 or Tier 1 criteria (i.e., those who do not meet the World Health

Table 1. Classification and description of age, sports type, sports performance level, and physical activity of the reference group.

Classification		Description	Example
Age	Older children	Average age of participants is 8–12 years.	
	Young adults	Average age of participants is 18–35 years.	
	Older adults	Average age of participants is over 60 years.	
Sports type	Individual sports	Individual sports are sports where participants mainly compete as an individual rather than as a member of a team, emphasising personal skills, performance, and stamina.	Fencing Swimming
	Team sports	Team sports are sports where participants work together as a team to compete against another team, emphasising collaboration, strategy, and collective effort.	Football Basketball
	Open-skilled sports	Open-skilled sports involve activities in which the environment is variable and unpredictable, requiring participants to adapt their movements in response to changing conditions.	Badminton Wrestling
	Closed-skilled sports	Closed-skilled sports involve activities in a stable and predictable environment, where athletes perform repetitive movements, focusing on perfecting a specific set of skills.	Gymnastics Swimming
	Aerobic sports	Aerobic sports involve activities where oxygen is sufficiently supplied to muscles for energy production over extended periods, improving cardiovascular function and endurance.	Tennis Triathlon
	Anaerobic sports	Anaerobic sports consist of short, high-intensity activities where the body's demand for oxygen exceeds the supply, relying on energy stored in muscles, enhancing strength and power.	Wrestling Gymnastics
	High-collision sports	High-collision sports involve significant physical interaction among participants, with frequent and forceful bodily contact.	Football Basketball
	Low-collision sports	Low-collision sports have minimal physical interaction between participants, where contact is either incidental or highly regulated.	Swimming Running
Sports performance level	Elite	Athletes competing at the national level (Tier 3) or the international level (Tier 4).	
	Non-elite	Athletes who identify with a specific sport and train with the purpose of competition (Tier 2).	
Physical activity of the reference group	Non-athletes	Non-athletes meeting the physical activity guidelines of World Health Organisation (Tier 1) or non-athletes who do not meet the guidelines (Tier 0).	
	Sedentary populations	Non-athletes not meeting the physical activity guidelines of World Health Organisation (Tier 0).	

Organisation physical activity standards (Tier 0) or who meet the physical activity standards for recreational purposes and do not focus on competition (Tier 1)) (McKay et al., 2022); 6. Studies published within the past 20 years (2004–2024); and 7. Reports written in English. The exclusion criteria are: 1. Fewer than ten participants in one group; 2. E-sports and chess athlete participants; and 3. Experimental training sessions that included physical activity. Two authors (CW & CZ) independently screened potential records based on these criteria. In cases of disagreement between CW and CZ during consultation, a third author (PA) was consulted to aid in reaching a resolution.

Data extraction and classification

All retrieved records were imported into EndNote X8 for initial organisation and systematic management. A predesigned table was then employed to extract key information from the studies included. The information was organised into three major sections: (1) basic information: author, publication year, title, journal, and country; (2) participant characteristics: sports, sports type (individual or team; open-skilled or closed-skilled; aerobic or anaerobic; high-collision or low-collision), sports performance level, physical activity of the reference group, sample size, training years and intensity, age classification, and gender; and (3) experimental characteristics: experimental task, description of the experimental procedure, and outcome measure. Specifics on age classification, sports type, sports performance level, and physical activity of the reference group are detailed in Table 1. Data was extracted by one author (CW), who reviewed the key information from each study at least three times. Another author (CZ) was responsible for verifying the accuracy of the data extracted. In cases of disagreement between CW and CZ during consultation, a third author (PA) was consulted to aid in reaching a resolution.

Risk of bias

The Risk of Bias Assessment Tool for Non-randomised Studies 2 (RoBANS 2), developed by Kim et al. (2013) and optimised by Seo et al. (2023), was employed to evaluate potential biases in the studies included. This tool assesses risk of bias across eight domains: Comparability of the target group, Target group selection, Confounders, Measurement of exposure, Blinding of assessors, Outcome assessment, Incomplete outcome data, and Selective outcome reporting. Each domain can be classified into one of three ratings: Low, Unclear, or High risk of bias. Two authors (CW & CZ) independently assessed the risk of bias for each included study. In cases of disagreement between CW and CZ during consultation, a third author (PA) was consulted to aid in reaching a resolution.

Statistical syntheses and analysis

RevMan 5.4 and Stata 18 were used for data analysis. Given the heterogeneity of the sample, a random-effects model was applied to calculate the standardised mean difference

(SMD) (Borenstein et al., 2021). This approach allows the findings to be generalised to a broader population from comparable studies. For studies reporting multiple WM outcomes, such as results from 2-back and 3-back tasks, the data were aggregated to yield a representation of WM performance. Additionally, the data from one included study that reported its findings in terms of median and range (Gokce et al., 2021) was converted into means and standard deviations (SD) using the mathematical methods described by Luo et al. (2018) and Wan et al. (2014). The small sample size was taken into account by adopting Hedges' g as a conservative estimate for the effect size, with interpretation following Cohen's guidelines where values of 0.2, 0.5, and 0.8 indicate small, medium, and large effect sizes, respectively (Cohen, 2013).

Performance in WM tasks in athletes and non-athletes was analysed with respect to two aspects: (1) WM accuracy or capacity, which signifies a participant's ability to process and retain information; and (2) WM reaction time, which reflects how quickly an individual processes information. Considering that the majority of the reviewed studies focused on WM accuracy or capacity, and because this outcome is more appropriate for evaluating participants' WM performance, WM accuracy or capacity was adopted as the primary outcome measure.

A forest plot was generated for graphical illustration of the size and distribution of the effect sizes across the included studies, along with the heterogeneity among studies. The SMD was calculated and used in a random effects model, with the DerSimonian-Laird method estimating the weighted average of these effect sizes, and the Knapp-Hartung method adjusting the standard error conservatively. The overall effect size was symbolised by a diamond, with its width spanning the 95% confidence interval (CI), and this serves as a visual representation of the estimation precision of the effect size. The lines extending from sides of the diamond represent the prediction interval (PI). The position of the diamond relative to the line of no effect indicates the effect direction, where a position leftward from the line denotes a non-athlete advantage and rightward denotes an athlete advantage, whereas an intersection denotes no significant difference. Statistical significance was assessed using a *P*-value threshold of less than 0.05. Heterogeneity was assessed using the I^2 statistic and the PI. I^2 represents the proportion of total variance attributable to true heterogeneity, while the PI estimates the range in which the effect size of a future study is likely to fall, reflecting the dispersion in effect sizes across studies.

A funnel plot was employed to assess publication bias, with SMD plotted against the standard error. Each data point on the plot represents both the effect size and its precision. The plot is framed by two lines that outline the pseudo 95% CI, and a line in the centre represents the mean effect size estimate for all included studies. The symmetrical distribution of data points around this central line serves as a visual indicator of publication bias. Complementing the visual inspection, Egger's and Begg's tests were used as statistical methods for assessing bias. The absence of significant publication bias was inferred only when both tests reported *P*-values greater than 0.10. In addition, a "leave-one-out" sensitivity analysis was conducted to examine the impact of individual effect size on the overall estimate.

Subgroup analysis was employed to investigate the impact of specific moderators on effect size estimate and to identify potential sources of heterogeneity. Data were assigned to designated subgroups exclusively when the original study provided sufficient details to support such categorisation. For studies that lacked sufficient information for subgrouping, their data were incorporated into the overall effect size estimate. Informed by an extensive review of the literature and guided by scientific expectation, seven moderators were identified for subgroup analysis: age, team and individual sports, open-skilled and closed-skilled sports, aerobic and anaerobic sports, high-collision and low-collision sports, elite and non-elite athletes, and physical activity of the reference group.

Results

Literature search results

A total of 4518 records were retrieved from seven databases. After removing duplicate records ($n = 2349$), 2169 records remained for preliminary screening. During the screening, 64 reviews, 54 animal studies, and six non-English records were excluded. Further screening of the titles and abstracts of the remaining 2045 records resulted in the exclusion of 1939 records. Detailed full-text assessments of the remaining 106 records led to the exclusion of 87 records for the following reasons: inconsistencies in research content ($n = 43$, referring to studies whose research content was not aligned with this meta-analysis), no relevant outcome measures ($n = 5$), absence of non-athlete participants ($n = 33$), absence of athlete participants ($n = 4$), and fewer than ten people in one group ($n = 2$). Two additional records were identified and included via reference checking. Therefore, a total of 21 records were ultimately included in this meta-analysis. The process used for literature identification, screening, and inclusion is outlined in Figure 1.

Study characteristics

A total of 21 studies were included in the meta-analysis, providing data on WM capacity or accuracy from 28 athlete groups and 21 non-athlete groups. Additionally, seven of these studies also assessed WM reaction time. These studies were published between 2010 and 2024, with 47.6% published after 2019, and 19 studies presented stimuli visually, while two presented them auditorily. The cumulative sample size reached 1455 participants,

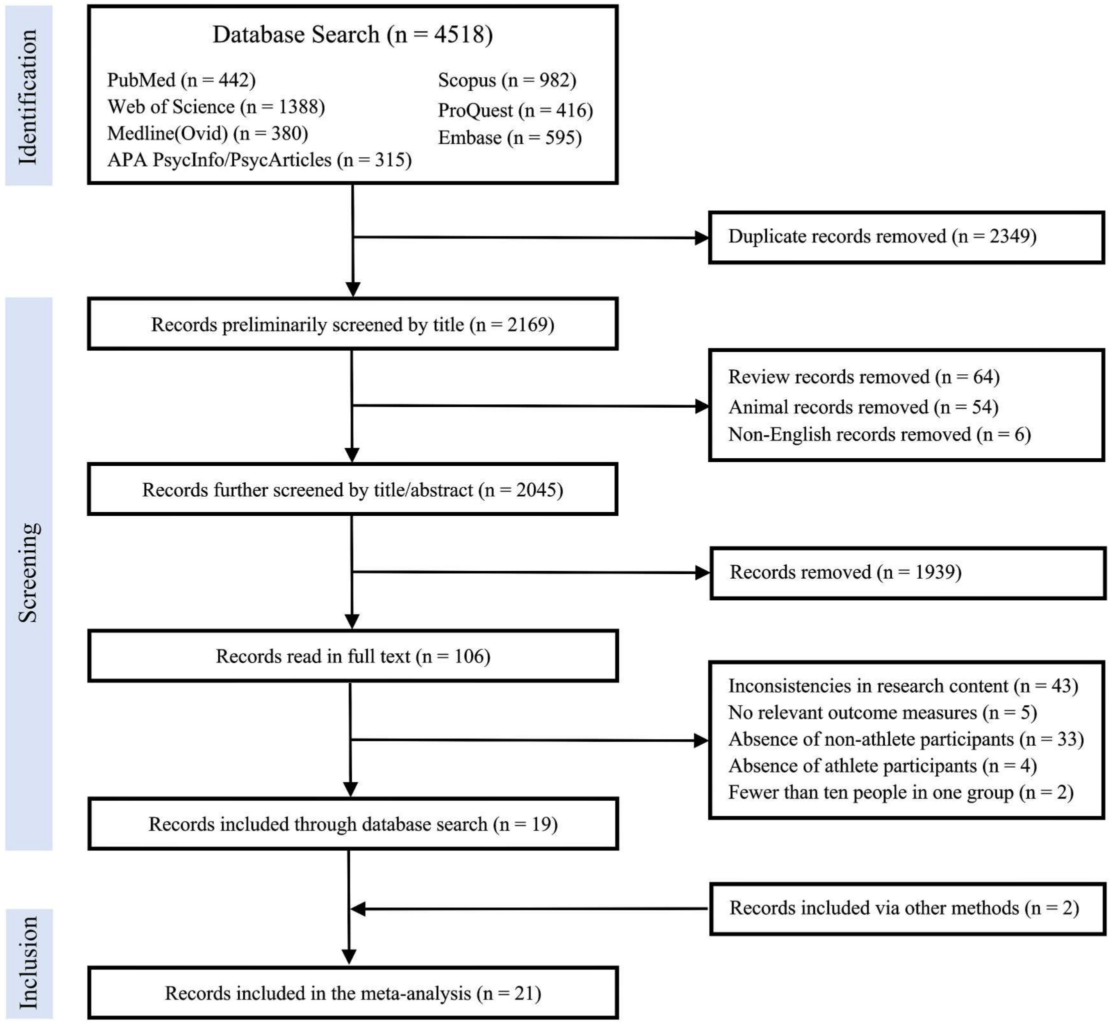

Figure 1. Flow diagram of literature identification, screening, and inclusion.

comprising 858 athletes and 597 non-athletes as the reference group. Females constituted approximately 39.3% of the overall sample. In terms of age distribution, two studies focused on older adults, while one study examined elite athletes, non-elite athletes, and non-athletes during late childhood. The remaining studies targeted young adults, with ages averaging from 18.13–28.9 years. The analysis covered a diverse range of sports, including basketball, football, swimming, badminton, and fencing. The athletes were also grouped by sports characteristics: 13 groups of team sports and 14 groups of individual sports; 20 groups of open-skilled sports and 7 groups of closed-skilled sports; 21 groups of aerobic sports and 5 groups of anaerobic sports; and 15 groups of high-collision sports and 12 groups of low-collision sports. Following the classification criteria for sports performance level proposed by McKay et al. (2022), 6 groups were classified in Tier 4 and 11 groups in Tier 3, and collectively recognised as elite athletes; another 11 groups were classified in Tier 2, indicating non-elite athletes. The classification of the reference group varied across studies: 8 original studies designated their reference group as sedentary according to McKay's Tier 0 criteria (Bull et al., 2020; McKay et al., 2022), whereas other studies did not specify whether their reference group met sedentary criteria. WM was assessed based on performance of several experimental tasks, including the N-back, Spatial span, and Corsi tests. More detailed information is provided in Table 2.

Risk of bias assessment

The results of RoBANS 2, presented in Figure 2, indicate that the included studies are generally of high quality. In particular, these studies are rated as low risk in the domains of Comparability of the target group, Target group selection, Measurement of exposure, Outcome assessment, and Selective outcome reporting, suggesting relatively unbiased design and implementation. Nonetheless, considerable uncertainty is evident regarding Blinding of assessors, which, with a rating of "Unclear", highlights the challenges in achieving effective blinding

Table 2. Characteristics of the studies included in the meta-analysis.

	Participants characteristics					
Study	Sample size (M/F)	Mean$_{age}$ ± SD	Participants type	Performance level	Experimental task	Note
Song et al. (2024)	Ath: 22 (9/13) Ref: 30 (13/17)	19.59 ± 0.28 18.13 ± 0.09	Badminton Non-athletes	Elite college level (Tier 2) NA	2 - & 3-back	Combined 2 - & 3-back results
Wang et al. (2023)	Ath: 42 (30/12) Ref: 45 (32/13)	20.46 ± 1.49 21.15 ± 1.69	Football Non-athletes	Elite college level (Tier 2) NA	Change detection	Experiments under meaningless condition
Nian et al. (2023)	Ath-a: 11 (11/0) Ath-b: 15 (15/0) Ref: 16 (16/0)	24.46 ± 1.43 22.33 ± 1.05 21.38 ± 1.67	Basketball Basketball Non-athletes	National level (Tier 3) Elite college level (Tier 2) NA	Digit span	
Manci et al. (2023)	Ath: 27 (27/0) Ref: 20 (20/0)	20.51 ± 2.31 21.20 ± 1.85	Basketball Sedentariness	National level (Tier 3) NA	Change detection	Combined different position players
Chen et al. (2023)	Ath: 26 (2/24) Ref: 26 (2/24)	20.2 ± 0.5 19.7 ± 0.9	Gymnastics/sports acrobatics/ … Non-athletes	Elite college level (Tier 2) NA	3-back	
Gokce et al. (2021)	Ath-a: 18 (9/9) Ath-b: 18 (9/9) Ref: 18 (7/11)	20.44 ± 1.85 21 ± 1.97 22.33 ± 1.94	Fencing Swimming Sedentariness	National level (Tier 3) National level (Tier 3) NA	Corsi's block tapping	Data converted from median and range
Lineweaver et al. (2020)	Ath-a: 17 (0/17) Ath-b: 19 (0/19) Ref: 26 (0/26)	19.77 ± 1.28 19.47 ± 1.26 19.46 ± 1.27	Football/basketball/volleyball Swimming/tennis/running track/ … Sedentariness	NCAA or club sport team (Tier 2) NCAA or club sport team (Tier 2) NA	Spatial span	
Vaughan et al. (2020)	Ath-a: 81 (47/34) Ath-b: 83 (48/35) Ath-c: 85 (49/36) Ref: 96 (56/40)	21.47 ± 1.91	Basketball/hockey/rugby/soccer Basketball/hockey/rugby/soccer Basketball/hockey/rugby/soccer Non-athletes	Super-elite (Tier 4) Elite (Tier 3) Amateur (Tier 2) NA	Spatial span	
Schaefer and Scornaienchi (2020)	Ath: 11 (8/3) Ref: 11 (5/6)	25.5 ± 2.6 23.6 ± 2.2	Table tennis Non-athletes	Tournament (Tier 2) NA	3-back	Auditory 3-back Data derived from figure
Schott and Krull (2019)	Ath: 20 (12/8) Ref: 20 (6/14)	76.5 ± 5.33 76.4 ± 5.96	Track and field Sedentariness	International master (Tier 4) NA	2-back	Data derived from figure
Chueh et al. (2017)	Ath-a: 16 (9/7) Ath-b: 16 (9/7) Ref: 16 (9/7)	20 ± 1.2 21.1 ± 2.3 20.7 ± 1.1	Badminton/table tennis Swimming/distance running/ … Non-athletes	National division 1 level (Tier 3) National division 1 level (Tier 3) NA	Delayed match-to-sample	Data derived from figure
Verburgh et al. (2016)	Ath-a: 69 (69/0) Ath-b: 48 (48/0) Ref: 51 (51/0)	10.6 ± 1.4 10.5 ± 1.3 10.4 ± 1.2	Football Football Non-athletes	Professional club (Tier 3) Amateur club (Tier 2) NA	VSTM forwards & backwards	Combined forward & backward results
Heppe et al. (2016)	Ath: 26 (13/13) Ref: 26 (15/11)	21.9 ± 3.81 22.0 ± 3.15	Football/volleyball Non-athletes	3rd & 1st national league team (Tier 3) NA	Memory span	Auditory memory Data derived from figure
Wang et al. (2015)	Ath: 12 (0/12) Ref: 13 (0/13)	20.58 ± 2.75 19.08 ± 2.10	Badminton Sedentariness	First prize in national college (Tier 3) NA	VSWM delay	
Tseng et al. (2013)	Ath: 12 (9/3) Ref: 12 (8/4)	72.4 ± 5.6 74.6 ± 4.3	Running Sedentariness	Regional & national rank (Tier 3) NA	ANAM	
Moreau (2013)	Ath: 18 (9/9) Ref: 18 (9/9)	22.8 ± 2.53 22.3 ± 2.44	Wrestling Sedentariness	National or international level (Tier 4) NA	No-suppression recall	Data derived from figure
Seo et al. (2012)						

(*Continued*)

Table 2. Continued.

	Participants characteristics					
Study	Sample size (M/F)	$Mean_{age} \pm SD$	Participants type	Performance level	Experimental task	Note
	Ath: 20 (0/20)	28.9 ± 7.33	Archery	International & national level (Tier 4)	Judgment of line orientation	
	Ref: 23 (0/23)	26.3 ± 4.56	Non-athletes	NA		
Moreau et al. (2012)	Ath: 30 (15/15)	22.3 ± 2.98	Fencing/judo/wrestling	International level (Tier 4)	Visual & spatial simple span	Combined visual & spatial span results
	Ref: 30 (15/15)	23.3 ± 4.04	Non-athletes	NA		
Zoudji et al. (2010)	Ath: 12 (12/0)	22 ± 3.09	Football	Top national level (Tier 4)	Visuospatial memorisation	
	Ref: 12 (12/0)	22 ± 2.13	Non-athletes	NA		
Pluncevic-Gligoroska et al. (2010)	Ath: 30 (12/18)	21.53 ± 4.98	Not reported	Competitive activities (Tier 2)	Digit span forward & backward	Combined forward & backward results
	Ref: 30 (14/16)	20.87 ± 3.52	Sedentariness	NA		
Furley & Memmert (2010a)	Ath: 54 (54/0)	24.8 ± 2.7	Basketball	≥ 4th highest league Germany (Tier 2)	Corsi's block tapping	
	Ref: 58 (58/0)		Non-athletes	NA		

Note: M: male; F: female; Ath: athletes group; Ath-a: athletes group a; Ath-b: athletes group b; Ath-c: athletes group c; Ref: reference group; NA: not applicable; NCAA: National Collegiate Athletic Association; VSTM: visuospatial short-term memory; VSWM: visuospatial working memory; ANAM: Automated Neuropsychological Assessment Metrics Battery. The figure data were derived using WebPlotDigitizer when they were not available in the article.

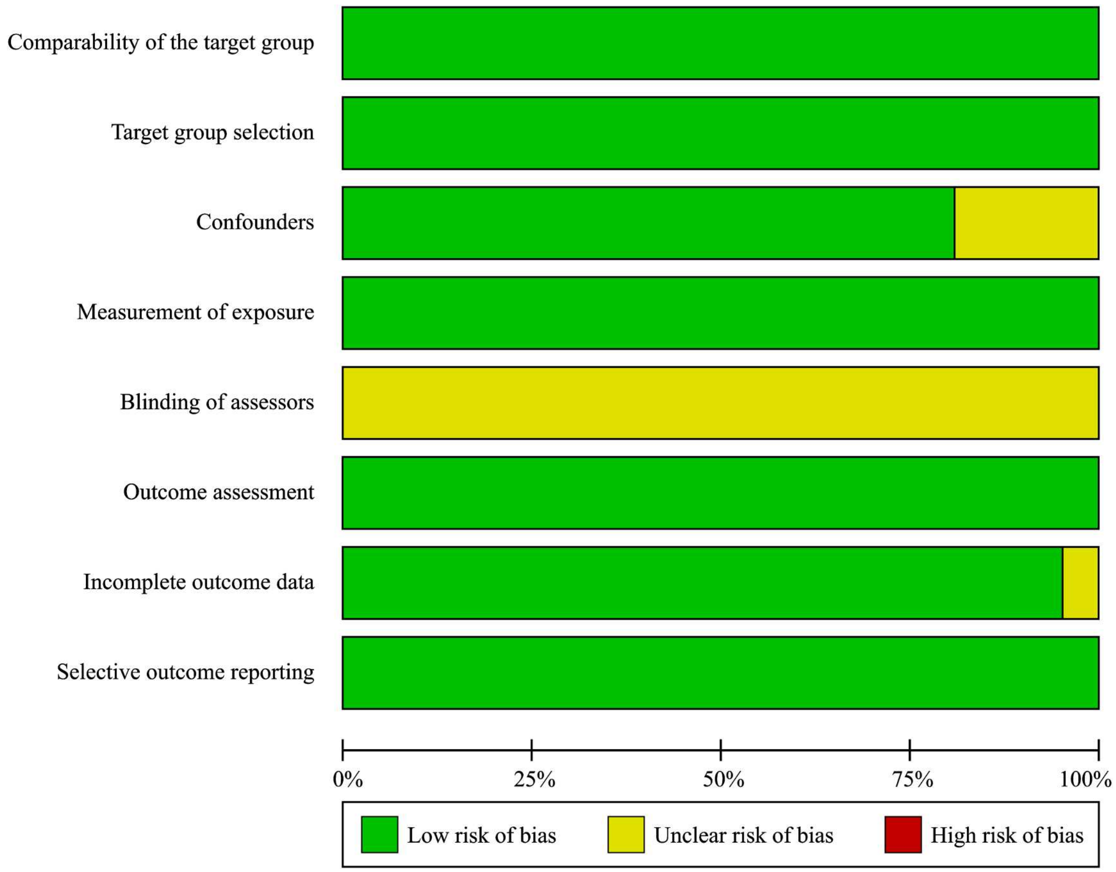

Figure 2. RoBANS 2 risk of bias proportional distribution across eight domains.

in cross-sectional studies. Regarding Confounders, most studies receive low-risk ratings, reflecting robust identification and adjustment for potential confounders that could skew WM performance. Notably, a minority of studies are graded as "Unclear" in the domain of Incomplete outcome data due to missing data, which could impact the precision of the findings. Comprehensive details on the risk of bias assessment are provided in the supplementary material.

Meta-analysis results

Heterogeneity test and overall effect size

Heterogeneity tests were conducted on the 21 included studies to assess effect size variability. The analysis revealed moderate heterogeneity ($Q = 44.36$, df = 20, $P = 0.001$, $I^2 = 54.92\%$, $Tau^2 = 0.074$, 95% PI [−0.30, 0.90]), indicating that the observed variability among effect sizes may partly be attributed to genuine differences across studies rather than chance errors. This degree of heterogeneity does not compromise the overall validity of the meta-analysis findings. The forest plot, arranged by descending publication year (Figure 3), delineates an overall effect size of 0.30 ($t = 3.37$, 95% CI [0.11, 0.48], $P = 0.003$). This result indicates a statistically significant, albeit small, advantage of athletes over non-athletes. The symmetrical distribution of effect sizes around the overall estimate supports the reliability of the meta-analysis findings. Although individual effect sizes often do not achieve significance, the accumulated evidence supports the hypothesis that athletes outperform non-athletes on WM tasks.

Publication bias results

Publication bias in the included studies was assessed by drawing a funnel plot (Figure 4) and by conducting Begg's and Egger's tests. The funnel plot exhibits satisfactory symmetry, although certain data points are situated on the periphery of the plot. Quantitatively, Begg's test yielded a Kendall's score of −2.00, with a standard error of 33.12. The Z-value was −0.09 and the *P*-value was 0.976. Egger's test indicated a coefficient of −0.10, with a standard error of 1.15, a t-value of −0.09, and a *P*-value of 0.932. Neither test provides statistical evidence of publication bias, as the *P*-values are well above the significance threshold. Additionally, sensitivity analysis confirmed the stability of the effect size estimate. Excluding individual studies did not materially alter the range of effect sizes or their 95% CIs, all of which remained to the right of the line of no effect. Further detailed information on the sensitivity analysis is provided in the supplementary material.

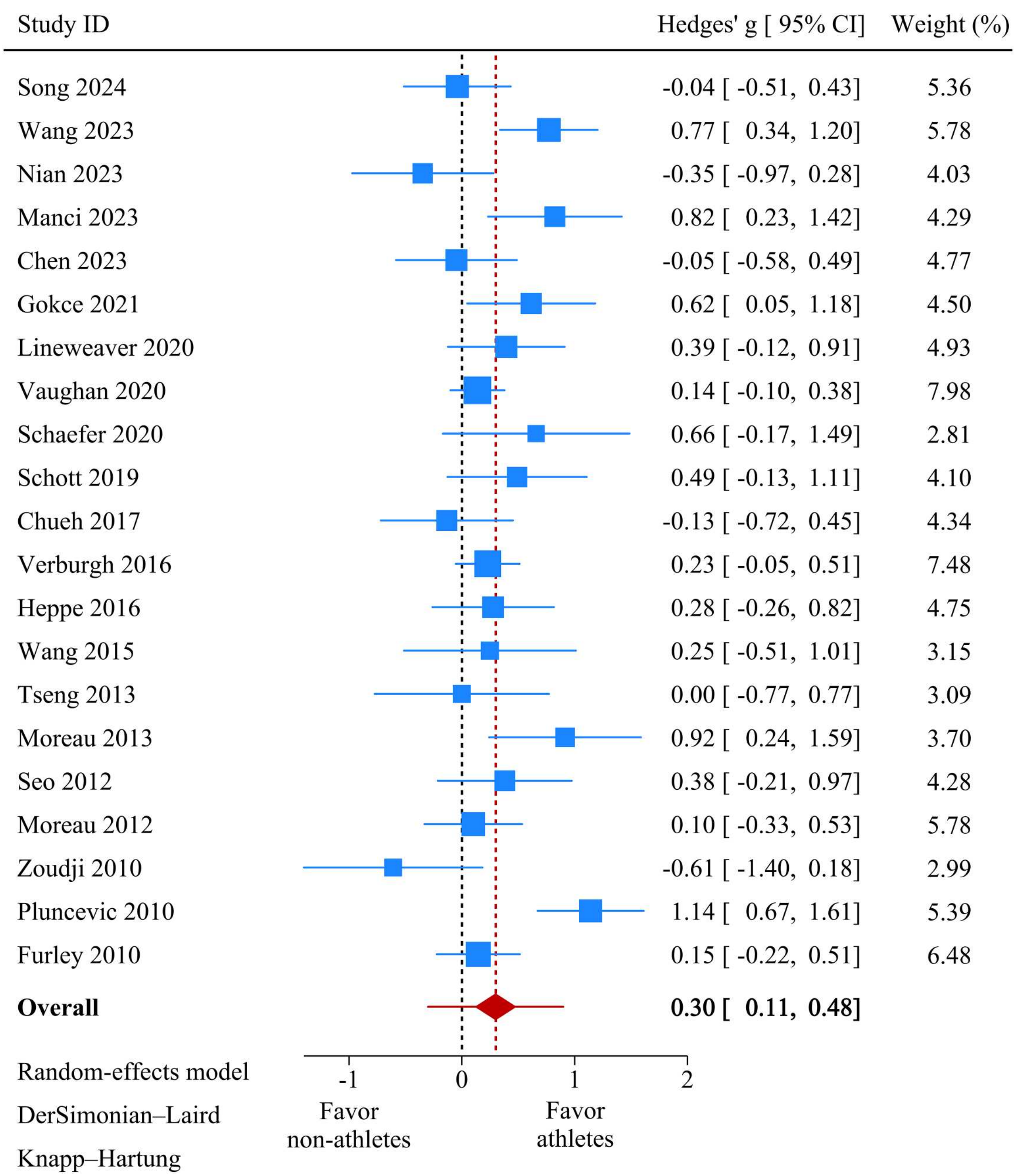

Figure 3. Forest plot of effect sizes and 95% CIs for WM performance.

Results of subgroup analysis

The impacts of various moderators on WM performance were investigated by subgroup analyses. Regarding age, the limited research on older adults and children was insufficient for robust statistical results; therefore, our focus was centred primarily on young adults. The subgroup analysis, covering 18 studies with 24 groups of athletes, revealed moderate heterogeneity ($I^2 = 60.72\%$, 95% PI [−0.39, 1.01]). The combined effect size for young adults indicated that athletes had a significant, albeit small, advantage in WM over non-athletes (Hedges' g = 0.31, $P = 0.009$).

Regarding sports type, the 12 studies included in the individual sports subgroup, involving 14 groups of athletes, exhibited low heterogeneity ($I^2 = 17.85\%$, 95% PI [−0.11, 0.66]). The combined effect size of this subgroup revealed a statistically significant, yet small, advantage of athletes over non-athletes in WM performance (Hedges' g = 0.27, $P = 0.016$). The team sports subgroup, which included nine studies involving 13 groups of athletes, revealed moderate heterogeneity ($I^2 = 56.18\%$, 95% PI [−0.42, 0.88]). Although athletes showed a numerically better WM performance than non-athletes, this was not statistically significant (Hedges' g = 0.23, $P = 0.122$). The comparison between team and individual sports subgroups did not show a significant difference ($Q = 0.11$, $P = 0.742$). In terms of sports skills, the open-skilled subgroup, comprising 16 studies with 20 groups of athletes,

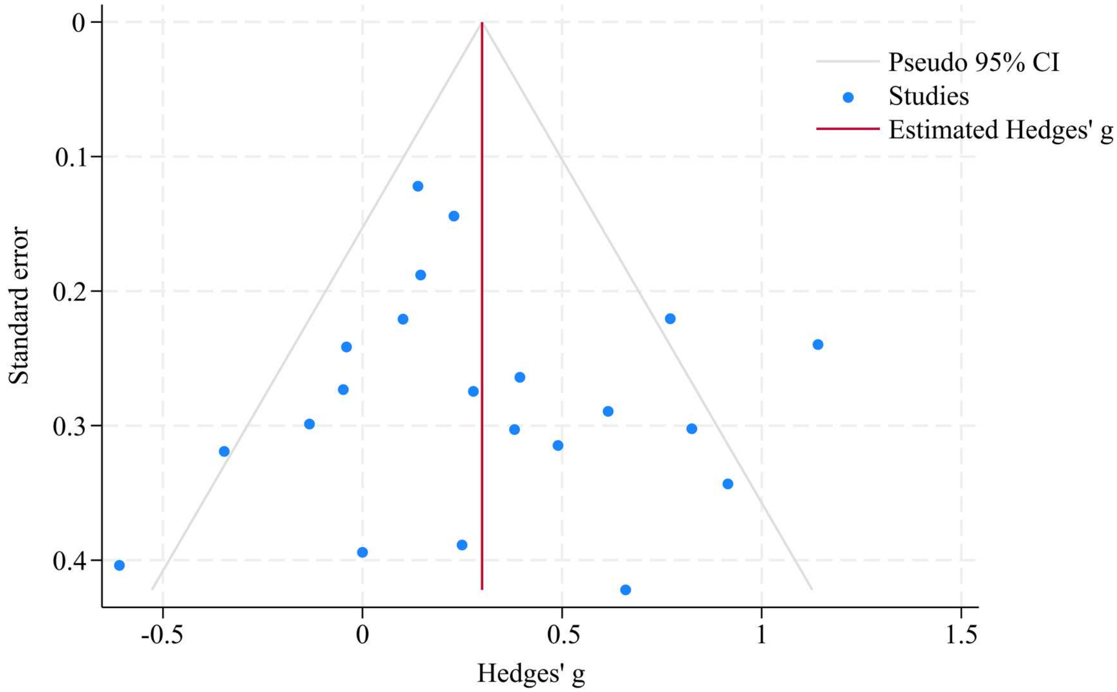

Figure 4. Funnel plot of publication bias for WM performance.

exhibited moderate heterogeneity ($I^2 = 46.44\%$, 95% PI [−0.27, 0.78]). The effect size analysis revealed a significant, although small, advantage for athletes over non-athletes in WM performance (Hedges' g = 0.25, $P = 0.018$). The closed-skilled subgroup, comprising seven studies, showed homogeneity ($I^2 = 0.00\%$). In this case, athletes had a higher WM performance than non-athletes, without reaching statistical significance (Hedges' g = 0.26, $P = 0.064$). The comparison between the two subgroups did not reveal a significant difference (Q = 0.00, $P =$ 0.951). For the metabolic characteristics of sports, the aerobic sports subgroup, comprising 15 studies that included 21 groups of athletes, exhibited low to moderate heterogeneity ($I^2 = 40.13\%$, 95% PI [−0.25, 0.69]). The combined effect size indicated a statistically significant, yet small, advantage for athletes over non-athletes (Hedges' g = 0.22, $P = 0.029$). The anaerobic sports subgroup, comprising only five studies, showed higher WM performance for athletes compared to non-athletes, but this was not statistically significant (Hedges' g = 0.36, $P = 0.111$), with moderate to high heterogeneity ($I^2 = 45.09\%$, 95% PI [−0.64, 1.37]). The test for subgroup differences was not significant (Q = 0.52, $P = 0.469$). Subgroup analysis based on the level of sports collision revealed that the low-collision sports subgroup, consisting of 10 studies with 12 groups of athletes, showed low heterogeneity ($I^2 =$ 2.22%, 95% PI [−0.01, 0.50]). Statistical analysis within this subgroup revealed a significant, yet small, advantage for athletes over non-athletes in WM performance (Hedges' g = 0.24, $P = 0.036$). The high-collision sports subgroup, consisting of 11 studies with 15 groups of athletes, displayed moderate heterogeneity ($I^2 = 55.70\%$, 95% PI [−0.36, 0.88]). Although athletes had numerically better WM performance than non-athletes, the difference was not statistically significant (Hedges' g = 0.26, $P = 0.060$). The comparison between the two subgroups did not reveal a significant difference (Q = 0.01, $P = 0.938$).

Analysis of sports performance level revealed moderate to high heterogeneity for the non-elite athletes subgroup, consisting of 10 studies with 11 groups of athletes ($I^2 =$ 66.56%, 95% PI [−0.50,1.09]). The combined effect size suggested that non-elite athletes were numerically better than non-athletes, with the result approaching statistical significance (Hedges' g = 0.30, $P = 0.052$). The elite athletes subgroup, comprising 14 studies with 17 groups of athletes, showed low to moderate heterogeneity ($I^2 =$ 38.57%, 95% PI [−0.25, 0.75]). Their WM advantage reached statistical significance (Hedges' g = 0.25, $P =$ 0.028). The test for subgroup differences was not statistically significant (Q = 0.08, $P = 0.771$). The reference group was also stratified according to their physical activity level. The non-athlete subgroup with unspecified physical activity levels consisted of 13 studies and exhibited low heterogeneity ($I^2 = 35.12\%$, 95% PI [−0.26, 0.56]). Athletes showed numerically higher performance than them, but the difference was not statistically significant (Hedges' g = 0.15, $P = 0.106$). The sedentary population within the non-athlete reference group included eight studies and displayed low to moderate heterogeneity ($I^2 = 30.82\%$, 95% PI [0.04, 1.22]). This population performed significantly more poorly in WM tasks than athletes (Hedges' g = 0.63, $P = 0.002$). Importantly, the effect size for the sedentary subgroup (athletes vs. sedentary population) was significantly larger than that of the non-athlete subgroup

Table 3. Summary of statistical results from subgroup analysis

Moderator	Subgroup	Effect size estimates				Heterogeneity						Subgroup differences	
		Hedges' g	*t*-value	95% CI	$P_{significance}$	Q-value	df	$P_{heterogeneity}$	I^2 (%)	Tau^2	95% PI	$Q_{between}$	$P_{between}$
Age	Young adults	0.31	2.97	[0.09, 0.53]	**0.009**	43.27	17	<0.001	60.72	0.099	[−0.39, 1.01]	Not applicable	
Sports type	Individual sports	0.27	2.85	[0.06, 0.49]	**0.016**	13.39	11	0.269	17.85	0.020	[−0.11, 0.66]	0.11	0.742
	Team sports	0.23	1.73	[−0.07, 0.53]	0.122	18.26	8	0.019	56.18	0.059	[−0.42, 0.88]		
	Open-skilled sports	0.25	2.66	[0.05, 0.46]	**0.018**	28.01	15	0.022	46.44	0.051	[−0.27, 0.78]	0.00	0.951
	Closed-skilled sports	0.26	2.27	[−0.02, 0.55]	0.064	5.55	6	0.476	0.00	0.000	Not applicable		
	Aerobic sports	0.22	2.44	[0.03, 0.42]	**0.029**	23.39	14	0.054	40.13	0.039	[−0.25, 0.69]	0.52	0.469
	Anaerobic sports	0.36	2.04	[−0.13, 0.86]	0.111	7.28	4	0.122	45.09	0.068	[−0.64, 1.37]		
	High-collision sports	0.26	2.12	[−0.01, 0.52]	0.060	22.57	10	0.012	55.70	0.061	[−0.36, 0.88]	0.01	0.938
	Low-collision sports	0.24	2.47	[0.02, 0.47]	**0.036**	9.20	9	0.419	2.22	0.002	[−0.01, 0.50]		
Sports performance level	Elite	0.25	2.48	[0.03, 0.47]	**0.028**	21.16	13	0.070	38.57	0.042	[−0.25, 0.75]	0.08	0.771
	Non-elite	0.30	2.24	[−0.00, 0.60]	0.052	26.91	9	0.001	66.56	0.101	[−0.50, 1.09]		
Physical activity of the reference group	Non-athletes	0.15	1.75	[−0.04, 0.34]	0.106	18.50	12	0.101	35.12	0.027	[−0.26, 0.56]	9.67	**0.002**
	Sedentary populations	0.63	4.86	[0.32, 0.94]	**0.002**	10.12	7	0.182	30.82	0.042	[0.04, 1.22]		

(athletes vs. non-athletes excluding the sedentary population) ($Q = 9.67$, $P = 0.002$). Detailed results for effect size estimates, heterogeneity, and subgroup differences are presented in Table 3.

Reaction time results

Reaction time in WM tasks was evaluated using a total of seven studies encompassing eight groups of athletes in the analysis. Due to the limited number of studies, the overall effect size estimate was emphasised. The results revealed high heterogeneity ($Q = 24.23$, $df = 6$, $P < 0.001$, $I^2 = 75.23\%$, $Tau^2 = 0.276$, 95% PI [−1.83, 1.11]), suggesting substantial variability among effect sizes. Despite the trend indicating faster reaction times for athletes over non-athletes, this advantage did not reach statistical significance (Hedges' $g = -0.36$, $t = -1.58$, 95% CI [−0.91, 0.20], $P = 0.165$).

Discussion

This meta-analysis investigated the differences in WM performance between athletes and non-athletes in non-sports-specific tasks. A comprehensive evaluation of 21 studies encompassing different age groups, genders, and sports types identified a small but statistically significant advantage in WM accuracy or capacity for athletes compared to non-athletes (Hedges' g = 0.30). Notably, this advantage was more pronounced when athletes were contrasted with a sedentary population (Hedges' g = 0.63), compared to the analysis where the sedentary population was excluded from the non-athlete reference group (Hedges' g = 0.15).

This research analysed the heterogeneity and its sources. The detected moderate heterogeneity prompted us to identify the underlying contributing factors. The selection of reference group emerged as an important source. Some studies opted for a sedentary population as the reference group (Gokce et al., 2021; Manci et al., 2023; Schott & Krull, 2019), whereas others might have employed individuals engaging in recreational physical activity (Heppe et al., 2016; Song et al., 2024). The analysis based on this grouping showed lower levels of heterogeneity within both subgroups. Furthermore, differences in participants' age, gender, sports performance level, and baseline cognition might contribute to the heterogeneity. Despite efforts to mitigate these issues by setting eligibility criteria, the intrinsic diversity among participants poses challenges. The inclusion of tasks like N-back and digit span, which engage different WM components, expanded the research scope but complicated result homogeneity. N-back, requiring continuous updating and greater cognitive effort (Kane et al., 2007), is more sensitive to detecting the cognitive benefits of sports, which involve dynamic decision-making and rapid adjustments during play. In contrast, digit span, with its lower cognitive complexity, may not fully capture these benefits, leading to smaller or less consistent effects. Additionally, some studies assessed other cognitive functions, such as attention (Chen et al., 2023) or visual search (Nian et al., 2023), which may have influenced capacity measurements and contributed to the observed heterogeneity, as these tasks engage different cognitive processes.

We conducted seven subgroup analyses as part of this study. An age-specific investigation revealed a small but significant advantage in WM for young adult athletes over non-athletes. However, our investigation into the link between sports expertise and WM across various age groups is limited by a lack of substantial research focusing on older adults and children. Therefore, we are unable to confirm whether older athletes exhibit superior WM enhancement in comparison to other demographic groups. Considering the benefits of exercise for mitigating age-related cognitive decline (Contreras-Osorio et al., 2022; Strömmer et al., 2017; Tseng et al., 2013), as well as its role in improving cognitive and learning abilities during childhood and adolescence (Contreras-Osorio et al., 2021), studies focusing on these age groups would be important. In particular, studies on older adults who are ex-athletes could provide insights into the long-term effects of sports.

Subgroup analysis based on sports types revealed that athletes from individual sports outperformed non-athletes in experimental WM tasks, while athletes from team sports showed no such significant advantage. Contrary to our expectations, no significant difference was found between individual and team sports subgroups in WM performance. These results suggest that the cognitive gains afforded by engaging in sports likely arise from general physiological and psychological effects. Additionally, the relatively higher heterogeneity among team sports may indicate variations in physiological or psychological demands across different sports. Dividing athletes into open- and closed-skilled groups revealed that only open-skilled athletes had an advantage over non-athletes, but both subgroups showed nearly identical effect sizes, with no significant WM difference between them. This observation contradicts the earlier hypothesis positing that open-skilled sports confer greater cognitive advantages due to their demands for adaptability and decision-making (Gu et al., 2019; Zhu et al., 2020). Although the uncertainty and variability of the external environment in open-skilled sports present broader cognitive challenges than in closed-skilled sports, requiring athletes to adapt and make quick decisions (Koch & Krenn, 2021), closed-skilled sports may foster cognitive skills, for example, by improving concentration. Moreover, the moderate heterogeneity of results related to open-skilled sports, contrasted with the homogeneity in closed-skilled sports implies that environmental changes and cognitive demands might contribute to the observed differences in effect size. Subgroup analysis indicated that aerobic athletes had a statistically significant advantage in WM tasks compared to non-athletes, whereas the anaerobic subgroup did not show such difference. Despite this, there was no difference in WM performance between the two subgroups. Our hypothesis regarding the superior benefits of aerobic sports was based on their potential to enhance cognitive function by augmenting cerebral blood flow and optimising neural connectivity (Dodwell et al., 2019; Smith et al., 2010; Stern et al., 2019). Although anaerobic sports have been less studied, the results suggest that they may also contribute to WM improvement, challenging the conventional emphasis placed on aerobic sports for cognitive benefits. This study also conducted a subgroup analysis to investigate the influence of collision risk on WM. Contrary to the hypothesis that intense physical contact in sports may compromise cognitive functions due to the risk of brain injuries, our findings indicated that collision risk may not significantly influence the cognitive benefits of sports expertise, as both subgroups exhibited similar effect sizes. Some studies support the notion that participation in high-collision sports does not necessarily impair cognitive function (e.g., Mayers et al., 2011; Oldham et al., 2022), while longitudinal research has not established a direct association between early involvement in collision sports and subsequent cognitive impairment (Weiss et al., 2021). These findings lead to the speculation that additional factors might moderate the comparison of WM across the collision-risk level. Further research is needed to comprehend how collision risk in sports influences WM and broader cognitive domains, with the aim of maximising cognitive benefits while mitigating potential negative effects.

Our comparison of WM performance of elite and non-elite athletes with that of non-athletes identified a WM advantage for elite athletes, while the advantage for non-elite athletes approached but did not reach statistical significance. Additionally, there was no significant difference in WM performance between the two subgroups. This finding prompts introspection regarding the sports performance-cognition nexus. Our results imply that cognitive benefits, particularly with respect to WM, stem more from sustained engagement in workout than from the high competitive level achieved (Sivaramakrishnan et al., 2024). Moreover, the comparable WM performance between elite and non-elite athletes suggests that improvements in WM tend to plateau after reaching a certain threshold. This observation is in line with earlier research positing that exercise benefits executive function by enhancing cerebral blood flow, facilitating connectivity between brain regions, and promoting neural adaptability, independent of the intensity of the activity (Guiney & Machado, 2013). Accordingly, this subgroup analysis underscores the significance of continued participation in workout over pursuing elite sports achievement.

When the reference group was grouped into non-athletes with unspecified physical activity levels and a sedentary population, a WM advantage was observed for athletes compared to the sedentary population (Hedges' $g = 0.63$). Moreover, the sedentary subgroup showed a significant disadvantage relative to the non-athlete subgroup. This finding underscores the cognitive benefits of exercise and may also reflect the potential cognitive drawbacks associated with sedentary lifestyles. Tseng et al. (2013) indicated greater gray and white matter densities in brain regions vital for visuospatial function, motor control, and WM (e.g., sub-gyral, cuneus, and precuneus regions) in individuals with lifelong exercise habits than in their sedentary counterparts. Furthermore, Raichlen and Alexander (2017) proposed a neurobiological hypothesis suggesting that a reduction in physical and cognitive activities through an energy-saving mechanism may lead to decreased neurogenesis and synaptogenesis, thereby causing diminished gray matter volume and localised brain atrophy. In addition, one study found that hypoxia is a "normal" state for the brain, and that running alone reduced the sedentary-induced hypoxic burden in mice by 52% (Beinlich et al., 2024). Sedentary lifestyles have been identified as a risk factor for various health issues, including obesity, cardiovascular disease, metabolic syndrome, cancer, and psychosocial problems (Park et al., 2020; Tremblay et al., 2010). Considering that nearly half of the global population leads a sedentary lifestyle (McKay et al., 2022), future studies are essential for investigating the effects of varying exercise intensity and frequency on WM and other cognitive functions.

The WM advantage observed in athletes in comparison to non-athletes is likely based on both physiological and psychological mechanisms. Physiologically, sports confer efficiency advantages in information processing and cognitive function by increasing cerebral blood flow (Kleinloog et al., 2023), triggering the release of brain-derived neurotrophic factor (Stillman et al., 2020; Zoladz et al., 2008), and promoting neural network plasticity (Voss et al., 2014). Psychologically, sports confer benefits that optimise cognitive performance through improved control, enhanced attention allocation, and accelerated information processing (Pesce et al., 2023; Sivaramakrishnan et al., 2024; Voss et al., 2010). This framework underscores the multifaceted impact of sports on cognitive function, including structural and functional enhancements of the brain at a physiological level, as well as strategic optimisation and efficiency in cognitive processes at a psychological level. The integration of these mechanisms supports the broad transfer hypothesis, indicating that sports expertise benefits not only the sports-specific domain but also general cognitive abilities.

From a broader perspective, these findings underline the value of incorporating structured sports programmes into the education system (Gearin & Fien, 2016). Beyond fostering physical health, such integration has the potential to improve learning efficiency and academic achievement (Bailey, 2006). Additionally, the importance of a multidisciplinary approach should not be overlooked. Integrating insights from sports science, neuroscience, psychology, and education (Fargier et al., 2017) enables a comprehensive examination of how sports impact WM and broader cognition. Advanced neuroimaging techniques provide a deeper understanding of the neural changes induced by sports training and the basis for designing effective sports-based cognitive intervention strategies (Moreau & Conway, 2014). Moreover, the role of socio-cultural factors in shaping individuals' engagement in specialised sports training is well-documented (Peter, 2015). Thus, the promotion of tailored sports programmes across diverse socio-cultural contexts should be investigated next. Understanding the preferences and barriers faced by different communities can assist in designing more inclusive and adaptable health promotion initiatives, encouraging wider participation in sports activities for cognitive benefits.

In discussing the limitations of this meta-analysis, it should be noted that RoBANS 2 indicates the included studies are of generally high quality, with minimal concerns in key domains, reinforcing the robustness of the findings. However, we acknowledge several aspects that may have impacted the interpretation and applicability of the findings. First, using diverse WM tasks enriched the research scope but also complicated results interpretation. In addition, the scarcity of studies on anaerobic and closed-skilled sports, as well as on specific age groups such as older adults and children, restricts the generalizability of our conclusions. Another limitation is the insufficient clarity regarding the physical activity levels of some reference groups, as 13 studies did not clearly report this information, which may include both active and sedentary individuals, limiting the comparison of WM between these populations. The cross-sectional design of the included studies prevents causal inferences about the effect of sports on WM and leaves open the possibility that individuals with better cognitive abilities are more likely to engage in sports. Similarly, weaker WM in sedentary individuals does not necessarily imply that a sedentary lifestyle causes WM decline; it may also reflect that those with lower WM capacity are more prone to sedentary behaviour. Longitudinal studies are needed to track athletes and sedentary individuals to clarify how sports and cognition interact over time. Lastly, although publication bias was assessed, it cannot be completely ruled out due to the possible omission of non-English and unpublished studies. Future studies should strive for consistency in WM tasks, extend investigations to include anaerobic sports, closed-skilled sports, and age groups across critical life stages, and adopt longitudinal or experimental methodologies to elucidate the causation between sports and WM.

Conclusion

This meta-analysis compared the WM performance of athletes to that of non-athletes. By integrating data from 21 studies involving 1455 participants, our study revealed a statistically significant, albeit small, advantage in WM for athletes compared to non-athletes (Hedges' $g = 0.30$). Moreover, this effect persisted across sports types and performance levels. Notably, this advantage was more pronounced when athletes were contrasted with a sedentary population (Hedges' $g = 0.63$), compared to the analysis where the sedentary population was excluded from the non-athlete reference group (Hedges' $g = 0.15$). Our findings indicate a consistent link between sports expertise and improved WM performance, while sedentary lifestyles appear to be associated with WM disadvantages. These results suggest the cognitive benefits of sports and emphasise the importance of an active lifestyle for enhancing cognitive health.

Open Scholarship

This article has earned the Center for Open Science badges for Open Data, Open Materials and Preregistered. The data and materials are openly accessible at https://osf.io/sgwp2/ , https://osf.io/sgwp2/ and https://www.crd.york.ac.uk/PROSPERO/display_record.php?RecordID=506333.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

Chenxiao Wu is supported by the China Scholarship Council (grant 202206060106). Chaoxiong Ye is supported by the Research Council of Finland (former Academy of Finland) Academy Research Fellow project (grant 355369) and Finnish Cultural Foundation (grant 00231373).

Contribution roles taxonomy

Chenxiao Wu: Conceptualisation (equal), Formal analysis (lead), Writing-original draft (lead), Visualisation (equal). Chenyuan Zhang: Formal analysis (equal), Validation (lead), Writing-Review & Editing (supporting). Xueqiao Li: Visualisation (equal), Writing-Review & Editing (equal). Chaoxiong Ye: Conceptualisation (equal), Supervision (supporting), Writing-Review & Editing (equal). Piia Astikainen: Conceptualisation (equal), Supervision (lead), Writing-Review & Editing (equal).

Data availability statement

The supplementary material, information table, and protocol for this study are available on the Open Science Framework at the following link: https://osf.io/sgwp2/.

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