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Does mental fatigue affect performance in racket sports? A systematic review

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Abstract

Mental fatigue impairs performance across several sports domains. However, a systematic review on its effects on racket sports performance has been lacking due to the previous scarcity of studies. This review aims to provide a comprehensive review the effects of mental fatigue on racket players' performance, with a discussion of the underlying mechanisms. A thorough search was conducted across five databases, including Web of Science, PubMed, SCOPUS, SPORTDiscus (via EBSCOhost), and the Psychological and Behavioral Science Collection (via EBSCOhost). The PICOS framework established the inclusion criteria: (1) healthy racket sports players; (2) induction of mental fatigue in both field and laboratory settings; (3) comparison of mental fatigue interventions with a control group (e.g., watching a movie or reading a magazine); (4) assessment of performance outcomes, including physical performance, skilled performance, and perceptual-cognitive performance; and (5) randomized controlled trials (RCTs), non-randomized controlled trials (non-RCTs), and non-randomized non-controlled trials. Mental fatigue manipulation, subjective evaluation, and (neuro)physiological markers were synthesized to support the successful induction of mental fatigue. Performance was categorized into tennis, table tennis, badminton, and padel based on the characteristics of specific racket sports domains. Secondary outcomes, such as the rate perception of effort (RPE) and motivation, were synthesized to explain the mechanisms based on the prominent theory of the Psychobiological model of endurance performance. Six studies revealed that mental fatigue impacts stroke performance in table tennis, affecting speed, accuracy, faults, and only second-serve accuracy in tennis. The response time of psychomotor performance increased in table tennis, padel, and badminton. Meanwhile, mental fatigue increased the RPE and remained unchanged in heart rate, blood glucose, and lactate, consistent with the Psychobiological model of endurance performance. Additionally, attention is suggested as a significant underlying psychobiological factor.

Keywords Mental fatigue, Racket sports, Performance, Mechanism, Thoery

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Introduction

Fatigue is a complex and multifaceted phenomenon associated with most acute and chronic illnesses and everyday life [1–3]. Peripheral fatigue, stemming from a peripheral standpoint, is commonly characterized as a decrease in the capacity to perform physical work following preceding physical effort induced by skeletal muscle [4]. In contrast, central fatigue, originating from a central perspective, is defined as a reduction in the ability to voluntarily activate muscles [5, 6]. However, recent discussions on fatigue in sports performance have expanded to encompass mental fatigue. Mental fatigue is a psychobiological state induced by prolonged, sustained cognitive tasks, accompanied by subjective feelings of “tiredness” and “lack of energy” [7, 8].

Mental fatigue detrimentally affects cognitive and physical performance in daily life [8]. Its impact on productivity [9] can potentially elevate the risk of traffic accidents [10], leading to significant adverse effects on human well-being [11]. Recently, mental fatigue has garnered attention in a sports context due to its reported impairment of performance. Initially, Marcora et al. observed a decrease in cycling time to exhaustion associated with mental fatigue [12]. Notably, this performance decline was attributed to individuals’ higher perception of effort (RPE) rather than cardiorespiratory and musculoenergetic mechanisms [12]. Following this framework, an increasing number of studies have investigated the influence of mental fatigue on performance in sports domains [13].

Van Cutsem et al. conducted a systematic review on the effects of mental fatigue on physical performance, concluding that mental fatigue impairs endurance performance [8]. They found that maximal strength, power, and anaerobic work remain unaffected [8]. While physical performance lays the groundwork for various sports activities, skilled performance directly influences competition outcomes. Sun et al., in their systematic report on mental fatigue’s impact on skilled performance, observed impairment not only in physical performance but also in skill performance in soccer, basketball, and table tennis [7]. Additionally, Habay et al. systematically synthesized studies on mental fatigue’s effects on sport-specific psychomotor performance (SSPP), noting that mental fatigue negatively affects decision-making, reaction time, and accuracy in SSPP [14].

Racket sports entail the utilization of a hand-held racket to propel a projectile between two or four players, with the objective of positioning the projectile where the opponent cannot successfully return it [15]. Prominent racket sports encompass tennis, badminton, squash, table tennis, and padel [10]. These sports are widely embraced for their accessibility and enjoyable nature, particularly appealing to inexperienced players, and have seen rapid development in sports [15]. However, to excel in racket sports, athletes must exhibit diverse qualities and attributes, employing a multifaceted interplay of technical, tactical, physiological, and psychological skills to attain peak performance [15]. Furthermore, players must concentrate their attention on tracking the ball or shuttlecock’s movement, foreseeing its path, and directing it towards the opponent’s side [16]. This prolonged cognitive involvement is often associated with mental fatigue in racket sports [17, 18].

Previous well-conducted reviews have extensively covered the impact of mental fatigue on various sports performances. However, these reviews have not included the latest studies on mental fatigue in racket sports due to time constraints of publication. In Sun et al.’s review, only one study [7] by Mansec et al. investigated the effects of mental fatigue on table tennis ball speed and accuracy [19]. To the best of our knowledge, the most relevant study on mental fatigue in racket sports performance is the review by Habay et al., which included three studies examining the effects of mental fatigue on table tennis ball speed and the performance of badminton players [14].

With the increasing number of studies delving into mental fatigue’s impact on racket sports performance, there arises a necessity for a systematic review that encompasses the latest research in this domain. Notably, certain facets of racket sports performance appear unaffected by mental fatigue. For example, Mansec et al.’s study indicated that mental fatigue decreased ball speed and accuracy in table tennis stroke performance [19]. Conversely, Kosack et al. discovered that mental fatigue did not affect specific skills among badminton players [20]. Similarly, Filipas et al. observed that mental fatigue impaired second serve accuracy but did not affect the speed of the first and second serves or the accuracy of the first serve in tennis [21]. These inconsistent findings underscore the necessity of a systematic review on the effects of mental fatigue on racket sports performance. On the other hand, the lack of a systematic review on mental fatigue in racket sports hinders practical understanding for coaches and players regarding the effects of mental fatigue on performance. Additionally, it limits the exploration of strategies to mitigate the performance decline induced by mental fatigue in racket sports.

According to the prominent theory proposed by Marcora et al. in the Psychobiological model of endurance performance, mental fatigue triggers the activation of the anterior cingulate cortex (ACC), resulting in elevated adenosine levels and decreased dopamine transmission [12]. This increase in adenosine causes mentally fatigued players to perceive effort more intensely, consequently resulting in a decline in subsequent performance [12, 22]. Sun et al. also proposed attention as a significant psychobiological factor affected by mental fatigue and sports performance [23, 24]. Considering the anterior cingulate cortex's (ACC) crucial role in attention regulation [25], the performance declines caused by mental fatigue may be associated with inadequate allocation of cognitive resources to attention, thus contributing to performance decline [26, 27].

The present review focuses on the effects of mental fatigue on the performance of racket sports. The primary aim is to delineate the effects of mental fatigue on various performance metrics among racket players. The secondary aim is to analyze underlying psychobiological factors, such as RPE, motivation, and attention, based on the Psychobiological model of endurance performance. This analysis aims to shed light on the mechanisms involved in mental fatigue and its potential influence on racket performance.

Methodology

This review adhered to the guidelines outlined in the Updated Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [28]. The protocol for this review was registered with the International Platform of Registered Systematic Review and Meta-Analysis Protocols (INPLASY), under registration number ID: 202320017.

Eligibility criteria

This review included peer-reviewed studies in English, with no limitations on publication year; the PICOS framework was used to establish eligibility criteria [29]. The inclusion criteria for this review were as follows: (1) Participants were healthy racket players, with no restrictions on the athlete's level. (2) Interventions could be conducted in both field and laboratory settings, provided that the studies clearly reported participants being under mental fatigue conditions and utilized subjective evaluations such as the fatigue visual analogue scale (F-VAS) and/or physiological markers like electroencephalography (EEG) to confirm the induction of mental fatigue. Additionally, secondary outcome measures focused on psychobiological markers such as RPE, motivation, and attention, which could elucidate the mechanisms behind mental fatigue and its potential impact on racket sports performance. (3) Comparisons involved participants in no mental fatigue conditions or placebo conditions. (4) Outcomes had to include at least one performance measure, with no restrictions on cognitive, physical, perceptual-cognitive skills, or skill performance. (5) The study design had to consist of peer-reviewed randomized controlled trials (RCTs), non-randomized controlled trials (non-RCTs), and non-randomized non-controlled trials published in reputable scientific journals.

Searching strategy and selection process

A systematic search was conducted on December 28, 2023, to identify studies on the effects of mental fatigue on racket sports performance. This search spanned five databases: Web of Science, PubMed, Scopus, SPORTDiscus (via EBSCOhost), and the Psychological and Behavioral Science Collection (via EBSCOhost). Where applicable, Medical Subject Heading (MeSH) terms were employed, and Boolean operators "AND" and "OR" were utilized across all databases. The detailed search strategy is provided in Table 1. Furthermore, to ensure thorough coverage of relevant studies, the reference lists of the included studies were examined, and a search was conducted on Google Scholar.

The study selection process is delineated in Fig. 1. After removing duplicates, two independent evaluators (CD and HS) screened studies based on titles and abstracts. Full-text screening was subsequently conducted according to predefined eligibility criteria. Disagreements were resolved through consultation with a third reviewer (KGS) until consensus was achieved.

Data extraction

Two independent reviewers (CD and HS) extracted data relevant to the aims of this review from the included studies, with accuracy validation by a third reviewer (KGS). The extracted information included:

1. First author's name and publication year.
2. Population characteristics: sample size, age, gender, and athlete level.
3. Intervention details: method of inducing mental fatigue, duration, subjective assessment of mental fatigue, secondary outcomes supporting mental fatigue, and physiological markers.
4. Outcome details: racket sports type, sports measurement domains, and performance outcomes.

Risk of bias assessment

The risk of bias for all included studies was assessed using the Revised Cochrane Risk of Bias (RoB 2.0). The RoB 2.0 is preferred over quality scales due to its greater reliability in assessing bias. This tool evaluate five domains of bias risk, categorizing as 'low risk of bias', 'some concerns', or 'high risk of bias risk' based on the signaling questions. An overall risk of bias was determined for each study. Two independent evaluators (CD and HS) assessed the bias of each included studies following the guideline from the Cochrane community. Any discrepancies were resolved through consultation with a third assessor (KGS), until consensus was reached.

Table 1 Number of hits for the complete strategy from difference databases

Databases	Complete searching string	Hits (28/12/2023)
Web of Science	(ALL=("mental fatigue" OR "mental exertion" OR "cognitive fatigue" OR "cognitive exertion" OR "mental exhaustion" OR "mental tiredness")) AND ALL=("racquet sports" OR "racket sports" OR "racket players" OR "Badminton" OR "Badminton players" OR "squash" OR "squash sport" OR padel OR "paddle tennis" OR "paddle" OR "padel players" OR "tennis" OR "Tennis player" OR "Table Tennis" OR "ping pong" OR "table tennis players")	22
PubMed	("mental fatigue"[All Fields] OR "mental exertion"[All Fields] OR "cognitive fatigue"[All Fields] OR "cognitive exertion"[All Fields] OR "mental exhaustion"[All Fields] OR "mental tiredness"[All Fields]) AND ("racquet sports"[All Fields] OR "racket sports"[All Fields] OR "racket players"[All Fields] OR "Badminton"[All Fields] OR "Badminton players"[All Fields] OR "squash"[All Fields] OR "squash sport"[All Fields] OR "padel"[All Fields] OR "paddle tennis"[All Fields] OR "paddle"[All Fields] OR "padel players"[All Fields] OR "tennis"[All Fields] OR "Tennis player"[All Fields] OR "Table Tennis"[All Fields] OR "ping pong"[All Fields] OR "table tennis players"[All Fields])	13
SCOPUS	(TITLE-ABS-KEY ("mental fatigue" OR "mental exertion" OR "cognitive fatigue" OR "cognitive exertion" OR "mental exhaustion" OR "mental tiredness") AND TITLE-ABS-KEY ("racquet sports" OR "racket sports" OR "racket players" OR "badminton" OR "badminton players" OR "squash" OR "squash sport" OR padel OR "paddle tennis" OR "paddle" OR "padel players" OR "tennis" OR "tennis player" OR "table tennis" OR "ping pong" OR "table tennis players"))	21
SPORTDiscus	("mental fatigue" OR "mental exertion" OR "cognitive fatigue" OR "cognitive exertion" OR "mental exhaustion" OR "mental tiredness") AND ("racquet sports" OR "racket sports" OR "racket players" OR "Badminton" OR "Badminton players" OR "squash" OR "squash sport" OR padel OR "paddle tennis" OR "paddle" OR "padel players" OR "tennis" OR "Tennis player" OR "Table Tennis" OR "ping pong" OR "table tennis players")	339
Psychological and Behavioral Science Collection	("mental fatigue" OR "mental exertion" OR "cognitive fatigue" OR "cognitive exertion" OR "mental exhaustion" OR "mental tiredness") AND ("racquet sports" OR "racket sports" OR "racket players" OR "Badminton" OR "Badminton players" OR "squash" OR "squash sport" OR padel OR "paddle tennis" OR "paddle" OR "padel players" OR "tennis" OR "Tennis player" OR "Table Tennis" OR "ping pong" OR "table tennis players")	38

Results

Study selection

A systematic literature search across five databases yielded 433 studies. After removing duplicates, 367 studies remained for further evaluation. Upon reviewing titles and abstracts, 284 studies were deemed inconsistent with the review's objectives. Subsequently, 83 studies underwent full-text assessment based on predefined criteria. Following meticulous evaluation, 6 studies met all inclusion criteria and were thus included in this review. The selection process was illustrated in Fig. 1.

Risk of bias

Five studies, which maintained research aim naivety among participants and adhered to randomized controlled trial guidelines, were assessed as "low risk" [19, 21, 30–32]. These peer-reviewed studies, classified in the low-risk category, investigated the impact of mental fatigue on racket sports performance and yielded compelling results. One study was rated as "some concern" due to insufficient details regarding the randomization process and outcome measurement [20]. While the author did not explicitly outline the randomization procedure, and the outcome measurement did not comprehensively capture badminton performance, the inclusion of countermovement jump and badminton-specific tests are crucial indicators of physical performance in badminton competitions [20, 33, 34]. Specific details are provided in Fig. 2.

Population characteristic

A total of 157 participants were included across all studies. Two studies examined male and female players [31, 32], while three focused solely on male players [19–21]. One study did not specify the gender of amateur padel players [30]. The age range varied from 18±4 [21] to 28.71±7.68 years old [30], and the participants' skill levels ranged from amateur [30] to elite [19]. Detailed characteristics of the included studies are presented in Table 2.

Mental fatigue intervention

Five studies employed the Stroop task to induce mental fatigue [20, 21, 30–32]. Van Cutsem et al. directed experienced badminton players to complete a 90-minute Stroop task [32]. Similarly, Kosack et al. and Habay et al. instructed badminton and table tennis players to undergo 60-minute Stroop tasks [20, 31]. Díaz-García et al. and Filipas et al. consistently instructed padel and tennis players to engage in 30-minute Stroop tasks [21, 30]. Mensec et al. investigated table tennis players' exposure to a 90-minute AX-continuous performance test (AX-CPT) [19]. Both the Stroop task and AX-CPT demand cognitive resources, involving sustained attention and response inhibition, which deplete cognitive resources [35]. Typically, sustained cognitive tasks exceeding 30 min successfully induce mental fatigue, with longer durations and inhibition process leading to heightened mental fatigue [7].

Control conditions varied across the studies. Three studies instructed participants to watch emotionally

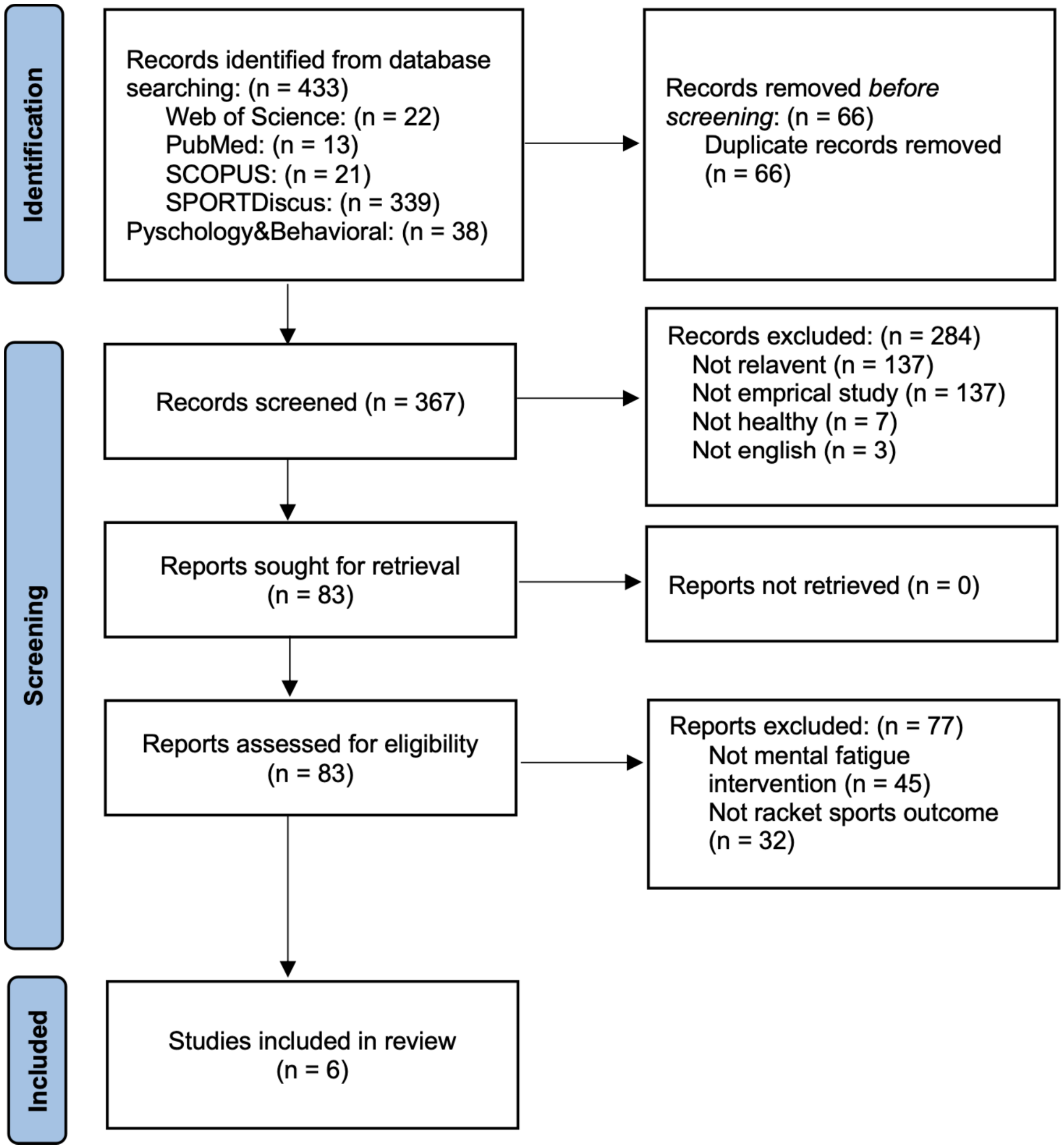

Fig. 1 Flow diagram of the study selection procedure

neutral documentaries [20, 31, 32], while one study had participants watch a movie [19]. One study employed easy cognitive tasks of equivalent duration to the mental fatigue intervention group [21].

Mental fatigue manifestation and mechanism factors markers

In six studies, subjective evaluation of mental fatigue was assessed using the mental fatigue Visual Analogy Scale (F-VAS) [19–21, 30–32], recognized as a reliable measure [35]. All six studies reported a significant increase in F-VAS scores after mental fatigue induction [19–21, 30–32].

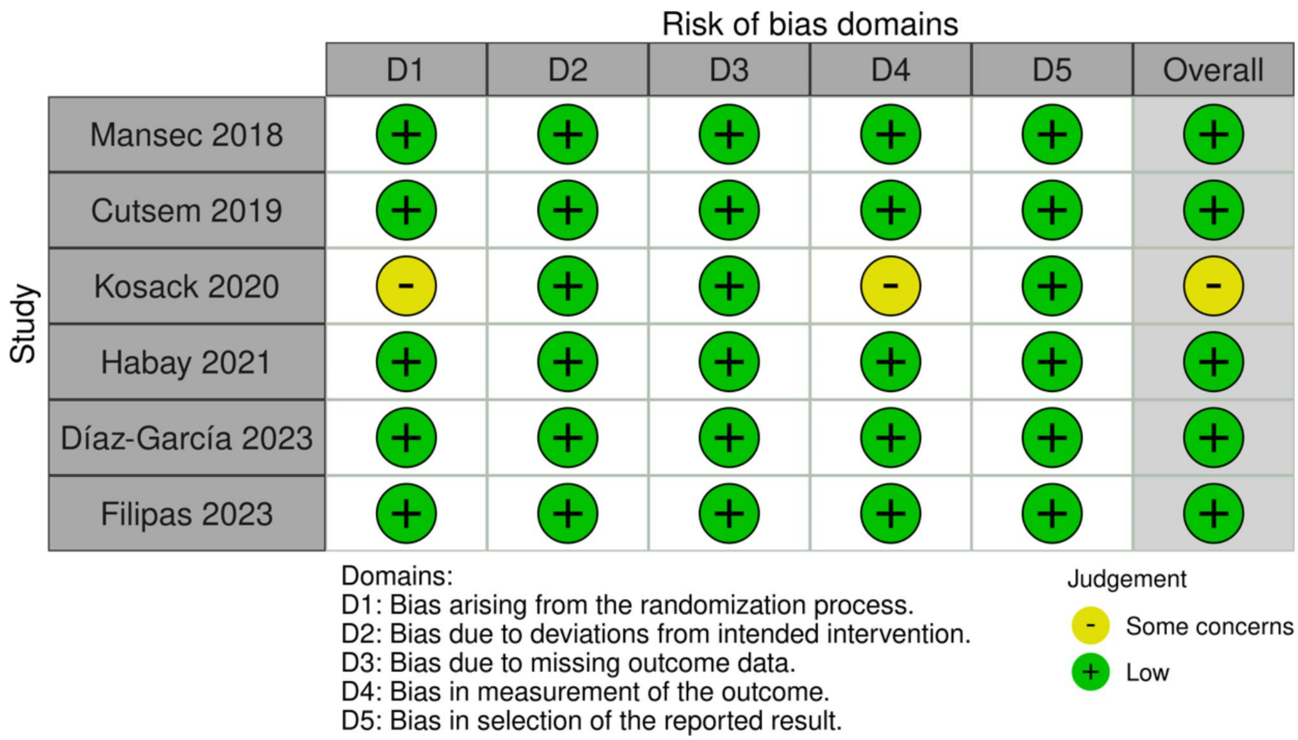

Fig. 2 Risk of bias summary for each included study

Table 2 Overview of included publication details

Study	Population characteristics	Intervention			Outcomes		
		Manipulation	Duration	Markers	Type of Sports	Performance Domain	Performance outcomes
Mansec et al., 2018	22 elites Sex: 22 ♂ Age: 26.9 ± 8.9 y	EG: AX-CPT CG: Watching movie	90 min	SE: F-VAS↑ PBM: RPE↑	Table tennis	Skill: Stroke	Ball speed↓; Accuracy↔ Faults↑; Total Score↓
Van Cutsem et al., 2019	11 experienced Sex: 5 ♂; 6 ♀ Age: 25 ± 4 y	EG: Stroop task CG: Documentary	90 min	SE: F-VAS↑; NASA-TLX: MD↑; PD↑;TD↑; Effort↑; Frustration↑; PBM: I-MO↔;S-MO↔ PM: HR↔;BG↔	Badminton	Perceptual-cognitive: Cognitive; Visuomotor	Flanker task Response time↑ Accuracy↔ Visuomotor task Response time↑
Kosack et al., 2020	19 elite Sex: 19 ♂ Age: 20 ± 2.8 y	EG: Stroop task CG: Documentary	60 min	SE: F-VAS↑; PBM: MO↔; Focus↔; RPE↔; PM: HR↔; BL↔	Badminton	Perceptual-cognitive: Physical; Specific skill	Countermovement jump height↔ Badminton-Specific duration↔
Habay et al., 2021	11 experienced Sex: 7♂; 4♀ Age: 24 ± 2 y	EG: Stroop task CG: Documentary	60 min	SE: F-VAS↑; NASA-TLX: Frustration↑ PBM: I-MO↓; S-MO↔; PRE↑ PM: HR↔ EEG upper α band↓;θ band↓;	Table tennis	Perceptual-cognitive: Cognitive; Visuomotor	Flanker task Response time↔; Accuracy↔; Visuomotor task; Reaction time↑;
Díaz-García et al., 2023	61 amateurs Age: 28.71 ± 7.68 y	EG: Stroop task CG: Control condition	30 min	SE: F-VAS↑; PM: Saccade latencies↓	Padel	Perceptual-cognitive: Cognitive;	Psychomotor vigilance task Reaction time↑
Filipas et al., 2023	10 professionals Sex: 10♂ Age: 18 ± 4 y	EG: Stroop task CG: Cognitive task	30 min	SE: F-VAS↑;	Tennis	Skill: Serve	First serve accuracy↔; Second serve accuracy↓; First serve speed↔; Second serve speed↔

y: Years; ♂: Males; ♀: Females; ↑: Significant higher; ↓: Significant lower; ↔: No significant difference; EG: Experimental Group; CG: Control Group; AX-CPT: AX-Continuous Performance Test; mins: Minutes; SE: Subjective Evaluation; PBM: Psychobiological Markers; PM: Physiological Markers; F-VAS: Fatigue Visual Analogy Scale; NASA-TLX: National Aeronautics and Space Administration Task Load Index; HR: Heart Rate BG: Blood Glucose; BL: Blood Lactate; EEG: Electroencephalography; I-MO: Intrinsic Motivation; S-MO: Success Motivation; MD: Mental Demand; PD: Physical Demand; TD: Temporal Demand; NA: Not Applicable

According to the Psychobiological model of endurance performance, RPE and motivation are critical factors influenced by mental fatigue, potentially impacting subsequent performance [12, 22]. Participants experiencing mental fatigue reported increased RPE, corresponding to decreased motivation [12, 22]. Three studies examined the RPE after mental fatigue induction, with two showing higher RPE compared to controls [19, 32]. Interestingly, Kosack et al. found no difference in RPE between conditions [20]. Regarding motivation, three studies investigated this aspect [20, 31, 32]. Van Cutsem et al. and Kosack et al. reported no significant difference in motivation between mental fatigue and control conditions [20, 32], while Habay et al. reported decreased motivation post-fatigue [31].

Physiological markers provide insights into mental fatigue mechanisms. During induction, Van Cutsem et al. monitored heart rate (HR) and blood glucose (BG). HR increased from 72±9 bpm to 77±9 bpm, while BG decreased from 93.8±6.7 mg/dl to 86.6±7.6 mg/dl [32], with no significant difference between groups. Similarly, Kosack et al. found no difference in HR or lactate levels [20]. Habay et al. used EEG and observed decreased α and θ band power post-test, indicating mental fatigue among table tennis players [31].

Racket sports performance outcomes

The performance outcomes for racket players across specific types of racket sports are summarized in Table 2, categorized into table tennis, badminton, padel, and tennis [19–21, 30–32].

Table tennis

Two studies investigated how mental fatigue affects table tennis performance. Mensec et al. focused on stroke performance, reporting that players experiencing mental fatigue exhibited a decrease in ball speed (-2.2% ± 3.5%), an increase in faults (+5.4±6.3%), and a decrease in total score (-6.6±8.9%) compared to controls [19]. Habay et al. explored mental fatigue's influence on visuomotor tasks and psychomotor performance, finding an increased reaction time (+70±7ms) in visuomotor skills among fatigued players [31, 34].

Badminton

Two studies examined the impact of mental fatigue on badminton performance. Van Cutsem et al. investigated badminton players' reaction time and psychomotor performance, while Kosack et al. focused on physical performance aspects [20, 32]. In terms of perceptual-cognitive performance, badminton players experiencing mental fatigue showed increased reaction times on the Flanker task ($p<0.05$) [32]. Additionally, there was an increase in psychomotor performance in visuomotor tasks, with mental fatigue participants reacting significantly slower to complex stimuli, leading to a decreased reaction time of visuomotor performance (1109±251ms) compared to the control group (1299±227ms) [32]. Kosack et al. concentrated on physical performance, specifically on the height of countermovement jump and badminton-specific performance [20]. However, no significant differences were found in countermovement jump height between the mental fatigue condition (0.41±0.07 m) and the control condition (0.40±0.06 m), nor in the duration of badminton-specific performance between the mental fatigue group (32.43±2.36 s) and the control group (32.43±1.96 s) among elite badminton players [20].

Padel

Díaz-García et al. studied the effects of mental fatigue on padel performance, particularly focusing on perceptual-cognitive aspects. Amateur padel players subjected to 30 min of mental fatigue through the Stroop task exhibited significantly slower reaction times on psychomotor vigilance tasks compared to controls ($p<0.001$) [30].

Tennis

Filipas et al. examined tennis stroke performance in professional players following a 30-minute Stroop task. They observed an increase in the percentage of failed second serves from the deuce side (14.9% ± 9.2% – 21.4% ± 9.9%) under mental fatigue conditions. However, no significant differences between the mental fatigue and control groups were found in first and second-serve speed or accuracy [21].

Discussion

The primary objective of this review is to synthesize and evaluate existing literature on how mental fatigue influences racket sports performance. A secondary aim is to explore mediators within the Psychobiological model of endurance performance [12, 22], validating Sun et al.'s proposition regarding attention as a critical psychobiological factor affected by mental fatigue and influencing subsequent performance [23].

The methods used to induce mental fatigue, including task type and duration, were critically examined. Subjective evaluations and physiological markers were used to confirm the presence of mental fatigue. Secondary factors such as RPE and motivation were considered potential psychobiological indicators of participants' mental fatigue status [12, 22].

Overall, cognitive tasks lasting over 30 min effectively induced mental fatigue, as evidenced by increased F-VAS scores [19–21, 30–32]. The F-VAS is validated as a straightforward and reliable measurement of mental fatigue. Smith et al. compared the Brunel Mood Scale, cognitive performance via a 3-minute Psychomotor

Vigilance Task (PVT), and physiological markers like electroencephalography (EEG) and heart rate variability (HRV), concluding that F-VAS is particularly effective for assessing mental fatigue [35].

Mental fatigue detrimentally affected stroke performance in table tennis and tennis [19], perceptual-cognitive performance in table tennis [31], badminton, and padel players [30, 32]. However, it did not impact physical performance metrics such as countermovement jump height and specific tests in badminton players [20]. These findings are consistent with the Psychobiological model of endurance performance [12, 22], which posits that impaired performance correlates with increased RPE due to mental fatigue [12, 22].

While direct measurement of attention was not consistently reported in the reviewed studies, physiological markers such as EEG waves and ERP amplitudes underscored attention's significance influenced by mental fatigue and subsequent performance outcomes [26, 31].

Mental fatigue intervention

Most of the studies included in this review focused on investigating the impact of mental fatigue on cognitive task performance within a laboratory setting [19–21, 31, 32]. The advantage of laboratory-induced mental fatigue lies in its ability to minimize confounding variables that could interfere with the outcomes [19–21, 31, 32]. The cognitive tasks employed varied from the Stroop task [20, 21, 30–32] to the AX-CPT [19]. Smith et al. compared different cognitive tasks including the Stroop task, AX-CPT, and psychomotor vigilance task, noting that all three tasks effectively induced mental fatigue [35]. They also suggested that tasks requiring response inhibition were particularly effective in inducing sustained mental fatigue compared to simpler cognitive tasks [35]. This finding underscores the importance of using cognitive tasks involving response inhibition in future studies on mental fatigue in racket sports, ensuring participants experience a genuine mental fatigue condition. Additionally, the duration of mental fatigue inducement ranged from 30 min to 90 min, consistent with Sun et al.'s recommendation of a minimum duration of 30 min for inducing mental fatigue [7, 13, 23, 24]. Thus, successful induction of mental fatigue involving cognitive tasks requiring sustained attention and response inhibition should last no less than 30 min.

In addition to laboratory-induced mental fatigue, there is a growing emphasis on inducing mental fatigue in field contexts [36–38]. In real-world scenarios, mental fatigue can vary based on factors such as competition level, type of sport, and individual differences [14]. Examining mental fatigue in field contexts could offer valuable insights for coaches and athletes, aiding in the comprehension of performance declines and the implementation of appropriate strategies to alleviate the effects of mental fatigue on performance. While this review did not encompass observational studies, it is worth noting that Díaz-García et al. explored mental fatigue induced in a field context [39], where padel players encountered consecutive World Padel competitions in a single day, resulting in prolonged reaction times on psychomotor vigilance tasks [39]. This discovery underscores the occurrence of mental fatigue in practical settings and its significance in comprehending performance obstacles within competitive sports environments [39].

Effects of MF on components of performance in racket sports

Mental fatigue on stroke performance of racket players

Mental fatigue adversely affected stroke performance in both table tennis and tennis serving [19, 21]. Mansec et al. conducted the primary investigation into mental fatigue's impact on table tennis stroke performance, revealing a decrease in elite players' ball speed (-2.2%) and accuracy (-3.9%), alongside an increase in faults (+5.4%) [19]. Given table tennis's heavy reliance on eye-hand coordination [40], previous research has often categorized this coordination as part of the execution function [41, 42], which was notably impaired by mental fatigue [7]. Duncan et al. highlighted mental fatigue's detrimental effect on manual dexterity performance [43], reinforcing the understanding that stroke performance suffers due to mental fatigue's impact on table tennis players' execution function.

Furthermore, stroke performance in table tennis was evaluated through the serve return, requiring players to concentrate their attention on the ball's path while suppressing irrelevant distractions [44, 45]. Boksem et al. theorized that individuals experiencing mental fatigue struggle to inhibit automatic attention shifts to irrelevant stimuli [46]. Kok et al. emphasized attention as a pivotal element in cognitive functioning [27]. Given that mental fatigue impairs executive functions such as inhibition and attention [47], limited cognitive resources for attention control could result in decreased stroke performance [26, 27].

Tennis, with its extensive history, serves as the cornerstone for various racket sports, yet limited research has examined mental fatigue's impact on tennis performance [48, 49]. Filipas et al. instructed the tennis players to 30 min of Stroop tasks to induce mental fatigue [21]. Interestingly, mental fatigue did not alter the accuracy and speed of first and second serves, but it did impair second serve accuracy [21]. As suggested by Filipas et al., executing a serve in tennis demands coordinated whole-body action to maximize power and speed [21]. This finding aligns with Van Cutsem et al.'s findings, indicating that mental fatigue does not influence maximal strength but does affect second serve accuracy in tennis [8]. Typically, players prioritize power over accuracy for their first serves, adjusting their focus to accuracy for the second serve due to the speed-accuracy trade-off [7, 50]. As a result, tennis players need to allocate more attentional resources to ensure the accuracy of their second serve while maintaining its speed, which might lead to compromised performance in second serve accuracy.

Mental fatigue on perceptual-cognitive performance of racket players

Habay et al. investigated the impact of mental fatigue on table tennis performance, focusing on perceptual-cognitive skills and physiological markers. They subjected table tennis players to a 60-minute Stroop task to induce mental fatigue, which resulted in a 9% increase in reaction time during visuomotor skill performance, indicating performance decline [31]. Visuomotor skills integrate perceptual and cognitive processes with motor behavior, requiring complex cognitive processing of sensory information in context [14, 51]. Mental fatigue among table tennis players led to decreased visuomotor performance, likely due to depleted cognitive resources affecting inhibition processes [23]. Additionally, Habay et al. identified reduced P3b amplitude as an ERP marker, suggesting compromised attention regulation under mental fatigue conditions [31]. Attention resources play a crucial role in performance, as emphasized by Kok et al., who proposed attention as the primary psychobiological factor influencing cognitive performance, with depleted resources resulting in inferior outcomes [27]. Sun et al. illustrated that mental fatigue in soccer players led to declines in decision-making performance, which nature scenes alleviated by restoring direct attention, metaphorically described as "letting effortful attention rest" [23, 24]. This restoration potentially allows more cognitive resources to be allocated to the task, suggesting attention's inclusion as a significant factor in the Psychobiological model of endurance performance [23].

Mental fatigue's impact on perceptual-cognitive performance extends beyond table tennis. Van Cutsem et al. reported that mental fatigue impairs the visuomotor performance of badminton players, who exhibited a 7% slower response time compared to controls [32]. This delay in visuomotor performance can be attributed to mental fatigue affecting executive functions and depleting cognitive resources in badminton players, hindering their ability to inhibit irrelevant stimuli and allocate attention effectively [46, 47].

In addition to table tennis and badminton, the perceptual-cognitive performance of padel players has been investigated. Although not included in this review due to study design constraints, Díaz-García et al. found that padel players exhibited increased reaction times on psychomotor vigilance tasks after participating in consecutive world padel tour matches [39], providing insights into mental fatigue in competitive contexts. Future studies exploring mental fatigue in field contexts could provide valuable insights for coaches and athletes. Díaz-García et al. also implemented brain endurance training to mitigate performance decline induced by mental fatigue in padel players, who showed decreased performance on psychomotor vigilance tasks following a 30-minute mental fatigue Stroop task [30]. This decline in cognitive performance reflects mental fatigue impairing padel players' executive function and depleting their cognitive resources, limiting their ability to exert inhibition and attention on the tasks.

Furthermore, Van Cutsem et al. observed that badminton players demonstrated superior visuomotor performance compared to healthy individuals [32]. Similarly, Díaz-García et al. noted that brain endurance training improved padel players' shot accuracy and speed even under mental fatigue conditions [30]. Additionally, Martin et al. found that professional cyclists displayed better inhibition abilities compared to recreational cyclists [52]. Sun et al. proposed natural exposure as a strategy to counteract mental fatigue, suggesting that direct attentional efforts and inhibition processes deplete cognitive resources [23, 53, 54]. Through self-control training, players enhanced their inhibition abilities, requiring fewer cognitive resources and thereby minimizing the impact of mental fatigue on subsequent performance [54]. These studies offer valuable insights into strategies for mitigating the effects of mental fatigue on performance, guiding coaches and racket players in selecting effective strategies to combat performance decrements caused by mental fatigue [53].

Mental fatigue on physical performance of racket players

Mental fatigue did not affect the physical performance of countermovement jump height or the duration of badminton-specific tasks among badminton players [20]. Factors such as players' movement and jump height play crucial roles in determining performance in badminton [55]. A quicker movement to the receiving position enhances the likelihood of scoring points [56], while greater jump height correlates with increased smash velocity and power output [57]. Kosack et al. instructed 19 national elite male badminton players to perform countermovement jumps following a warm-up session [20]. However, no significant difference in physical performance was observed after inducing mental fatigue between the mental fatigue and control groups [20]. This finding is consistent with Van Cutsem et al.'s research, which showed that mental fatigue unaffected maximal strength [8].

Kosack et al. also assessed badminton performance using a specific test involving ten sets of twenty corner movements, where players swiftly navigated from the central position to designated corners on a computer screen, striking sensors at each corner [20]. Kosack et al. noted that there was no significant difference in the performance of the badminton-specific test between the mental fatigue group and the control group [32]. They indicated that this test primarily assesses badminton-specific fitness, which heavily relies on anaerobic capacity [32]. This finding supports Van Cutsem et al.'s study, suggesting that mental fatigue does not influence badminton players' maximal strength and anaerobic performance. However, further research examining the effects of mental fatigue on specific skilled performances, such as smash stroke accuracy and speed, would provide valuable insights into its impact on badminton performance.

Psychobiological markers and potential mechanism

Consistent with Marcora et al., mental fatigue did not result in notable changes in physiological markers such as heart rate, lactate levels, and blood glucose concentrations [12]. The Psychobiological model of endurance performance suggests that mental fatigue triggers activity in the anterior cingulate cortex, leading to increased adenosine levels and reduced dopamine transmission. This physiological response heightens racket players' perception of effort, identified as a primary psychobiological factor influencing performance outcomes [12, 22]. Studies reviewed here support this model, indicating that players experiencing mental fatigue reported heightened perception of effort, which correspondingly impacted performance decline. Future research investigating the effects of mental fatigue on subsequent performance should consider the principles outlined in this Psychobiological model of endurance performance.

Additionally, Sun et al. propose attention as a crucial psychobiological factor to integrate into the model [23]. Drawing from the Strength Model of Self-Control [58], they suggest that players utilize and deplete finite cognitive resources for both cognitive and physical tasks [23, 58, 59]. Depletion of these resources results in an inability to sustain performance, contributing to performance decline induced by mental fatigue [59]. Habay et al. found significant interactions over time and regions of interest (ROI) across upper alpha, lower alpha, and theta bands, indicating that mental fatigue led to reduced power levels in table tennis players [31]. Given the overlap in the anterior cingulate cortex (ACC) involvement in attention and mental fatigue [25], the noted decrease in alpha and beta power suggests diminished attention [60, 61]. Furthermore, Guo et al. discovered that music mitigated mental fatigue, as evidenced by a substantial decrease in P3 amplitude of ERPs during mental fatigue conditions [26]. This reduction suggests that mental fatigue compromised participants' ability to allocate attention resources, leading to performance decrements [26].

Meanwhile, Sun et al. proposed that exposure to natural scenes counteracted mental fatigue by restoring directed attention (effortful attention), thereby preserving more cognitive resources to alleviate performance decline [23]. These studies highlight attention as a significant psychobiological factor mediating the relationship between mental fatigue and performance. However, further research is needed to explore and validate this psychobiological factor proposed by Sun et al.

Limitation and future directions

This review encountered several limitations despite an exhaustive search and meticulous methodology. Firstly, the lack of sufficient studies prevented conducting a meta-analysis, underscoring the necessity for more comprehensive investigations to establish robust findings regarding the impact of mental fatigue on racket players' performance, considering the variability among players. Secondly, the predominant focus on psychomotor performance in the reviewed studies overlooked crucial aspects such as ball speed, accuracy, and spin, which significantly influence competitive outcomes in racket sports. Addressing these performance metrics in future research would provide valuable insights for coaches and athletes, aiding in refining training and competition strategies.

Additionally, including elite players across diverse disciplines could offer a more nuanced understanding of how mental fatigue manifests under intense competitive conditions. This knowledge is crucial for coaches and players in devising effective strategies to mitigate performance decrements attributed to mental fatigue. Moreover, while the aim of this review was to systematically synthesize the effects of mental fatigue on racket sports performance, all included studies investigated mental fatigue induction in laboratory settings, contrary to expectations for field-based investigations. This gap suggests a need for further studies examining field-based mental fatigue induction to draw more relevant conclusions for practical contexts.

Furthermore, future studies employing subjective measurements of mental fatigue should ensure participants are informed about its definition [35], as prior knowledge may mitigate confounding factors such as boredom affecting subjective evaluations of mental fatigue [62, 63]. Lastly, additional research is warranted to explore the underlying mechanisms of mental fatigue, particularly the role of attention as a significant but currently underexplored psychobiological factor, as suggested by Sun et al. Investigating these comprehensive mechanisms linking mental fatigue and performance could facilitate targeted strategies to mitigate its effects and thereby counteract performance decrements.

Conclusion

Mental fatigue has been demonstrated to negatively impact perceptual-cognitive performance, particularly in visuomotor reaction time among badminton and table tennis players, as well as reaction time in psychomotor vigilance tasks among padel players. Additionally, mental fatigue impairs stroke performance, notably affecting ball speed and accuracy in table tennis, and decreasing accuracy in the second serve of tennis players. However, mental fatigue did not significantly influence first and second serve speeds in tennis, first serve accuracy in tennis, or countermovement jump height and shuttle run performance in badminton players. These findings underscore the detrimental effects of mental fatigue on performance in racket sports, emphasizing the need for coaches and practitioners to address and mitigate its impact proactively.

Strategies to counteract mental fatigue and subsequent performance decrements should be actively pursued. The Psychobiological model of endurance performance provides a promising framework for future investigations in this area. Furthermore, insights from physiological markers such as EEG waves and ERP amplitudes, as suggested by Sun et al., highlight attention as a significant psychobiological factor influencing these effects. Integrating attention into the Psychobiological model of endurance performance could enhance understanding of the complex relationship between mental fatigue and sports performance. However, comprehensive research is necessary to fully elucidate this intricate mechanism.

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Author contributions
DC, HS, KGS and SR conceptualised the review, created aims and established inclusion and exclusion criteria. DC SDC and YZ conducted the database searches and all screening in accordance with the inclusion criteria. DC performed assessment for the risk of bias with HS and KGS and wrote the initial draft. KGS and HS supervised the study and contributed to analysis. SR, SDC and YZ contributed to reviewing and editing. All authors were involved in interpreting the data, critically revising the manuscript, and approve the final version for publication.

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Data availability
The datasets generated during and/or analysed during the current study are available from the corresponding author upon reasonable request.

Declarations

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Not applicable.

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The authors declare no competing interests.

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