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SYSTEMATIC REVIEW

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Methodological Considerations and Effectiveness for Ecologically Valid Mental Fatigue Inducement in Sports: A Systematic Review

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Abstract

Background Mental fatigue (MF) in sports has developed from well-controlled laboratory-based studies to applied studies with greater ecological validity. Ongoing developments in the representativeness of MF inducement approaches, including the broad range of sport-specific motor tasks to simulated real-life scenarios, have shown methodological variability and inconsistent outcomes of effectiveness. Evaluating and comparing these approaches is essential to provide recommendations for designing inducement tasks in future research and considerations for practitioners. Therefore, the systematic review aimed to summarize more ecologically valid MF-inducing tasks in representative sports contexts and to evaluate the MF inducement effectiveness via manipulation check outcomes and potential after effects on subsequent sport-specific performance.

Methods The review was registered on the PROSPERO database (CRD42024577183). PubMed, Web of Science, PsycINFO, and SPORTDiscus were searched until 21 August 2024 for studies that applied acute, more ecologically valid MF-inducing tasks within sports-specific contexts. The MF inducement task design and effectiveness across representative sports and participants were investigated.

Results Twelve papers were included. Only a quarter of studies presented an overall low risk of bias. The 20-minute sports-specific motor tasks with cognitive demands and most 30-minute simulated real-life scenarios (i.e., social media use on smartphones, watching tactical videos, sports-themed videogame play) successfully induced MF in differing athlete samples. Ineffective MF inducement was attributed to shorter task duration, passive engagement with sparse cognitive demands, or the involvement of less susceptible participants.

Conclusions This systematic review evaluated MF inducement methodologies with greater ecological validity to sporting contexts. The inducement effectiveness varied within four task types. Athletes and sports practitioners should carefully manage the modality and content of pre-competition activities to minimize MF. Future research should refine and co-design the MF-inducing task with practitioners based on multifaceted MF evidence from

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laboratory and real-life settings, create immersive scenarios that can better replicate the inducement process in specific contexts, and improve measurement tools, which will provide comprehensive evaluation and verification of the MF inducement.

Key Points

- The review indicated that 20-minute sports-specific motor tasks with cognitive demands and the majority of the 30-minute simulated real-life scenarios (i.e., social media use on smartphones, watching tactical videos, sports-themed videogame play) successfully induced mental fatigue (MF) in differing athlete samples.
- A shorter duration, passive engagement with sparse cognitive demands, or inclusion of less susceptible participants, caused ineffective MF inducement derived from real-life scenarios, highlighting the need for athletes and sports practitioners to carefully manage the modality and content of pre-competition activities to minimize MF where optimal performance is desired.
- Future research should co-design inducement tasks with practitioner and researcher input based on multifaceted MF evidence from laboratory and real-life settings, create immersive scenarios that can better replicate the inducement process in specific contexts, and improve measurement tools, which will provide comprehensive evaluation and verification of the MF inducement.

Keywords Mental fatigue, Cognitive fatigue, Inducement, Ecological validity, Representative, Methodology, Sports context, Real-life scenario

Background

Mental fatigue (MF) is a psychobiological state caused by high cognitive effort [1], which results from cognitive load [2]. High cognitive load can be from prolonged activity of low difficulty/complexity or short-time demand activity of high difficulty/complexity [3]. Tiredness, lethargy, and a lack of energy with possible impaired executive function and/or physical performance characterize MF [4]. This domain has gained significant attention in sports contexts over the last decade [5]. Laboratory-based studies indicate the detrimental effects of MF on subsequent athletic performance, especially on physical endurance performance [6, 7], sport-specific psychomotor performance [8], and team-sports technical/tactical performance [9–11]. As research on MF progresses within the sports domain, questions arise regarding methodological approaches to inducing MF. Typical MF inducement methods, such as computerized key-pressing tasks (e.g., Stroop task, AX-Continuous Performance Task), have been critiqued for limited ecological validity [12, 13]. The lack of similarity to tasks understood in daily training or competition decreases the representativeness and applicability of these findings for use in real-world sports settings.

In response, some methodological considerations and developments attempt to enhance the ecological validity of MF-inducing tasks. Ecological validity refers to tasks that closely resemble the characteristics of a realistic sporting environment [14]. Taking the soccer training protocols as an example, a 20-minute whole-body coordination task that consisted of juggling a tennis ball while stepping on the agility ladder was designed to induce MF before small-sided games took place [15]. The successful inducement of MF was subjectively identified through higher cognitive demands when compared with light general aerobic exercises. Furthermore, an adapted 20-minute repeated soccer-specific skill test (i.e., Loughborough soccer passing test, LSPT) including passing, dribbling, controlling, and decision-making process was developed [16]. The randomized verbal order of the unexpected passing targets made the task more mentally demanding than executing the same motor pattern in a fixed, clockwise order. These attempts integrate specific technical movements and corresponding cognitive processes to varying degrees, incorporating representative challenges of time pressure and dynamic environments.

Besides the specific sports training and competition, many sport- and non-sport-related situations imposing a high cognitive demand can also elicit MF [4]. For a better understanding of real-life cognitive activities encountered by athletes, the survey of English academy soccer players reported that MF was experienced primarily as a result of match-play, but other factors such as travel, fixture congestion, and study also contributed to the moderate presence of subjective MF [17]. Beyond the soccer context, athletes and staff across multiple elite sports also identified MF caused by additional media demands, study, and work commitments [12]. Relevantly, daily commutes to training facilities (e.g., driving the car, riding the motorcycle or bicycle) may generate cognitive load from the complex traffic conditions, which could induce MF in athletes [12, 18, 19]. When closer to the match, athletes' common activities like pre-match music, browsing social media, watching videos, and team meetings may also play a role in mental expenditure [17, 20]. Such insights help inform what cognitively demanding tasks athletes may undertake prior to training and competition, and which may be inducing of MF and its subsequent performance effects. The representative scenarios could be extracted and simulated for MF inducement design in real-world settings and to investigate the after effects on performance. Advantageously, the MF research domain in sports has developed from well-controlled laboratory-based studies with high internal validity to applied studies with more real-world validity [4].

Ongoing developments and applications, including the broad range of sport-specific motor tasks to simulated real-life scenarios, combined with methodological variability of the specific manipulation and evaluation, have contributed to inconsistent outcomes of effectiveness. For instance, a 30-minute smartphone use could induce MF in professional soccer players and impair passing decision-making performance [21], while a longer exposure of 45 min caused no behavioral and perceptual changes in amateur triathletes [22]. Similarly, the 30-minute smartphone use-induced MF could negatively affect subsequent 100/200-meter swimming, but have no impact on 50-meter swimming [23]. As the research progresses in broader sports contexts, it is necessary to systematically review, summarize, and evaluate the novel methodological applications for MF inducement purposes with more ecological validity across specific sports. Therefore, the review aims to: (1) summarize more ecologically valid MF-inducing tasks and the representative sports contexts, and (2) evaluate the effectiveness of MF inducement tasks via manipulation check outcomes and potential after effects on subsequent sport-specific performance. By evaluating methodological aspects across sports with a standardized perspective, this review will provide applied recommendations for inducement methodologies of future studies, which may have significant implications for advancing knowledge and practice.

Table 1 PICOS overview

Population	Healthy adults (18–50 years) with sports experience or athletes of all ages
Interventions	Single, acute mental fatigue-inducing task with ecological validity (a dynamic motor task including representative elements to replicate sports reality, or the simulated real-world scenarios encountered by athletes for mental fatigue inducement) before the corresponding specific sports activity
Comparisons	Periods/activities that intended to induce non- or less mental fatigue, or traditional laboratory computerized key-pressing tasks
Outcomes	Manipulation check of mental fatigue inducement effectiveness (with subjective/behavioral/(neuro)physiological measurements); athletic performance on subsequent sport-specific tasks as a supplementary behavioral marker
Study Design	Original experimental research

Methods

This systematic review was registered on PROSPERO (CRD42024577183) and conducted by following the PRISMA (Preferred Reporting Items for Systematic Review and Meta-analyses) guidelines [24].

Eligibility Criteria

The predominant objective of this systematic review was to examine the methodology of more ecologically valid MF-inducing tasks within the context of specific sports. The MF inducement task design, the inducement effectiveness, the representative sports and participant characteristics were investigated. In the current review of the acutely induced MF state, the maximum of one day (i.e., 24 h) was set as the cut-off of the longest MF-inducing task duration to differentiate from the chronic MF or MF trait [25, 26]. Any other multifaceted fatigue concept (e.g., burnout) was excluded. Due to the inconsistent terminology used in this field to describe mental fatigue state, cognitive fatigue, self-control strength depletion, and ego depletion were accepted as possible equivalent concepts at first screening [6].

To establish the detailed search strategy for this systematic review and the inclusion criteria, the PICOS categories (Population, Intervention, Comparison, Outcomes, and Study design, see Table 1) were applied for screening titles, abstracts, and/or the full text of papers.

The eligible population included healthy adults (i.e., aged 18–50 years) with sports experience as well as all-age athletes (i.e., no age limit for participants with defined athletic identity). The experimental intervention was an acute ecologically valid task with the purpose of MF inducement for its after effect verification. This review detailed the novel MF inducement application as either a dynamic motor task including representative elements to replicate sports reality or real-world scenarios encountered by athletes for MF inducement before the corresponding specific sports activity. Clinical interventions, concurrent interventions (e.g., MF inducement combined with muscular fatigue, sleep deprivation, nutrition, or heat condition), long-term single intervention over 24 h, or repeated interventions that last more than one day were excluded. For the control condition, periods/activities that intended to induce non- or less mental fatigue, or traditional laboratory computerized key-pressing tasks were set for the MF inducement comparison.

Since the effectiveness of the MF-inducing intervention was the primary aim for review outcomes, manipulation checks of MF within expected tasks were necessary for the inclusion. Consistent with other reviews in this domain, three markers of induced MF were categorized into (1) subjective perception (e.g., self-reported MF on a scale); (2) behavior (e.g., cognitive/physical/technical performance); (3) (neuro)physiological measurement (e.g., brainwave activity on electroencephalogram (EEG)) [8, 27]. The successful inducement of the MF state was defined as the significant alteration of at least one marker immediately after the experimental intervention [27]. Considering the individual differences in MF susceptibility [28], the subsequent sport-specific performance was examined between conditions as a supplementary behavioral marker for the MF inducement effectiveness, if the manipulation check failed. Studies that entirely neglect manipulation check sessions were excluded.

Regarding the study design, only original experimental research was included. The sports specificity of the subsequent performance task needed to be consistent with the represented sports context of MF inducement. Where this was not the approach, for example, studies that used inconsistent isometric movement tasks (e.g., wall-sit), local motor tasks (e.g., bench press, lower limbs maximum voluntary contraction), general physical capacity screening (e.g., balance, dexterity), or other static computerized tasks that lack sports specificity (e.g., video-based visual task, static virtual task) following MF-inducing interventions, were excluded.

Table 2 Keyword strings applied to the databases and the hits results for the complete search strategy

Database	Keywords string + applied filter (language: English)	Hits by 21 August 2024
PubMed	(("mental fatigue"[MeSH]) OR ("mental fatigue") OR ("cognitive fatigue") OR ("mental strain") OR ("cognitive strain") OR ("mental exertion") OR ("cognitive exertion") OR ("ego depletion")) NOT ("patients" OR "burnout" OR "animals" OR "mice" OR "rats" OR "stroke" OR "traumatic brain injury" OR "multiple sclerosis" OR "Parkinson" OR "diabetes" OR "disease" OR "Neoplasms" OR "Infections")	2573
Web of Science	ALL=(("mental fatigue") OR ("cognitive fatigue") OR ("mental strain") OR ("cognitive strain") OR ("mental exertion") OR ("cognitive exertion") OR ("ego depletion")) NOT ALL=("patients" OR "burnout" OR "animals" OR "mice" OR "rats" OR "stroke" OR "traumatic brain injury" OR "multiple sclerosis" OR "Parkinson" OR "diabetes" OR "disease" OR "Neoplasms" OR "Infections")	3597
PsycINFO	(("mental fatigue") OR ("cognitive fatigue") OR ("mental strain") OR ("cognitive strain") OR ("mental exertion") OR ("cognitive exertion") OR ("ego depletion")) NOT ("patients" OR "burnout" OR "animals" OR "mice" OR "rats" OR "stroke" OR "traumatic brain injury" OR "multiple sclerosis" OR "Parkinson" OR "diabetes" OR "disease" OR "Neoplasms" OR "Infections")	1689
SPORTDiscus	TX ((("mental fatigue") OR ("cognitive fatigue") OR ("mental strain") OR ("cognitive strain") OR ("mental exertion") OR ("cognitive exertion") OR ("ego depletion"))) NOT TX (("patients" OR "burnout" OR "animals" OR "mice" OR "rats" OR "stroke" OR "traumatic brain injury" OR "multiple sclerosis" OR "Parkinson" OR "diabetes" OR "disease" OR "Neoplasms" OR "Infections"))	1182

Information Sources and Search Strategy

The literature sources used in this review included PubMed (best match option), Web of Science (all databases searched), PsycINFO, and SPORTDiscus database. All databases were searched and updated up to the 21st of August 2024. Filters applied were: English language and article/peer-reviewed journal paper publication. Table 2 reports an overview of the keyword strings used in the different databases and the results. In addition, the reference lists of included studies were screened to ensure the search was as exhaustive as possible.

Study Selection and Data-Collection Process

After executing the search strategy of keywords and filters, all studies from the four different databases were gathered and imported into Rayyan [29]. After removing duplicates, two authors (CB and AM) screened the studies by checking titles and abstracts independently and blinded from each other. The system combined decisions from the two reviewers, and any "Maybe" or "Conflict" was double-checked and resolved with author EL. Following the first stage, the screening process progressed with two authors (CB and AM) who assessed the remaining full-text articles against the inclusion criteria for eligibility. Where disagreement still existed after a mutual discussion, authors BR and SR made the final decision.

Extracted Information and Variables of Interest

According to the purposes of the review, the methods section of the selected studies was first screened. Extracted details included: the representative sports contexts and participant characteristics, the detailed MF-inducing task design, the control condition(s), the subsequent sport-specific task, and the manipulation check of the MF inducement. Additionally, the outcomes of the manipulation check sessions and the potential after effects of induced MF on specific athletic performance were extracted for further evaluation of MF inducement effectiveness. Any significant changes were categorized into subjective, behavioral, or (neuro)physiological markers.

Risk of Bias Assessment

According to an overview of the study design, the Revised Cochrane Risk of Bias tool for randomized trials (RoB 2) [30] was considered suitable and utilized to assess the risk of bias in each study by two authors (CB and AM) independently. As provided in the tool, each of the five general bias evaluation dimensions received a rating that was either “low risk”, “some concerns”, or “high risk” of bias. Subsequently, an overall judgment was made. The authors adhered to the guidelines from the Cochrane community. Any disagreement from both sides was resolved through discussion and consensus with another author (EL).

Results

The full study selection process is presented in Fig. 1. The database search resulted in 9041 hits, of which 5660 remained after the duplicates were excluded. The remaining titles and abstracts were then screened, leading to the thorough assessment of 48 full-text papers for eligibility. Ultimately, 12 papers were included in the review.

Study Quality

Half of the included studies showed an overall risk of bias with some concerns, and 25% were with high risk (see Fig. 2 within the study and Fig. 3 across studies). The main issue regarding the randomization process was the lack of double-blind manipulation when allocating the participants and examiners to conduct the MF inducement. Moreover, the acquiescence bias from the respondents' self-reported MF and the expectancy effect from

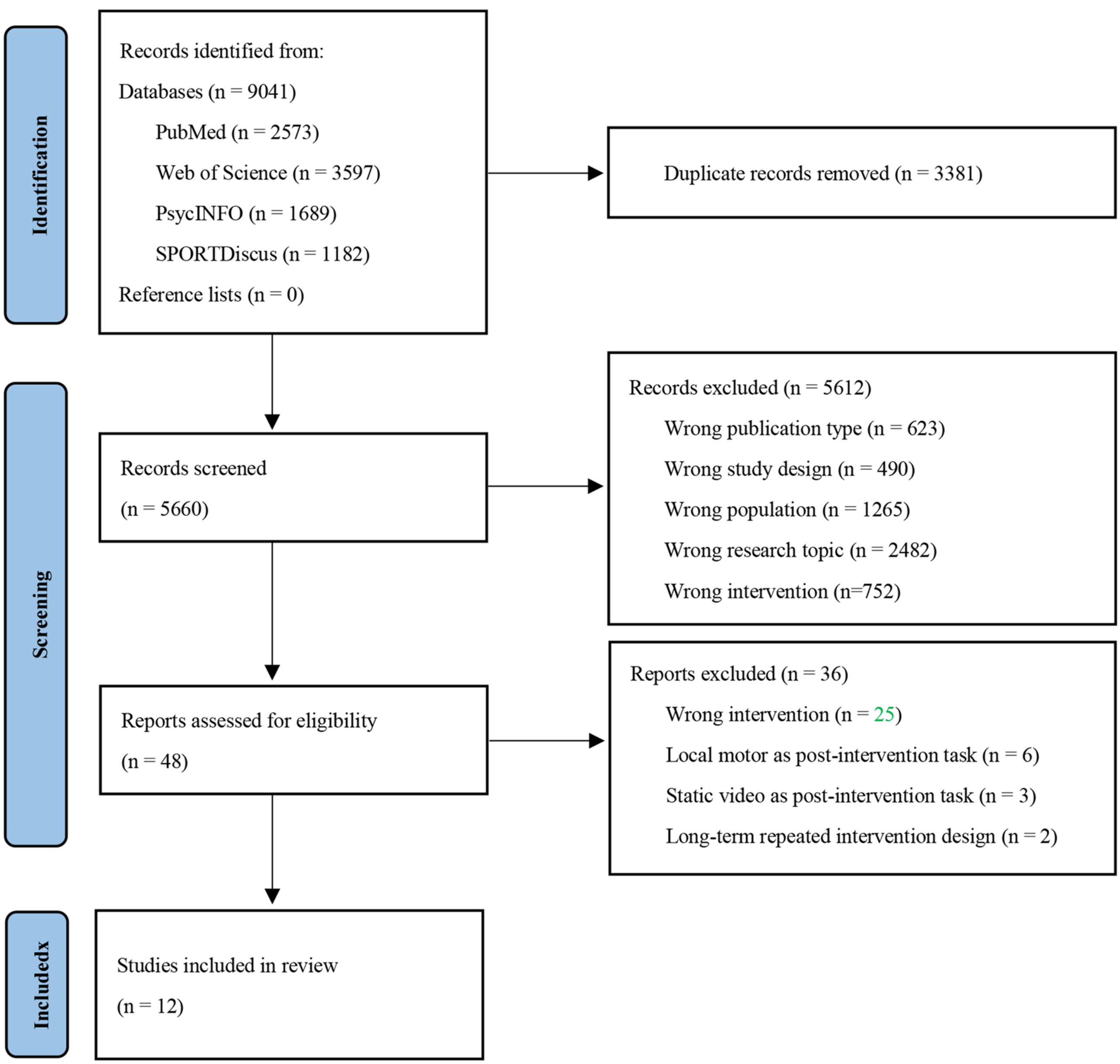

Fig. 1 Flowchart of the selection process

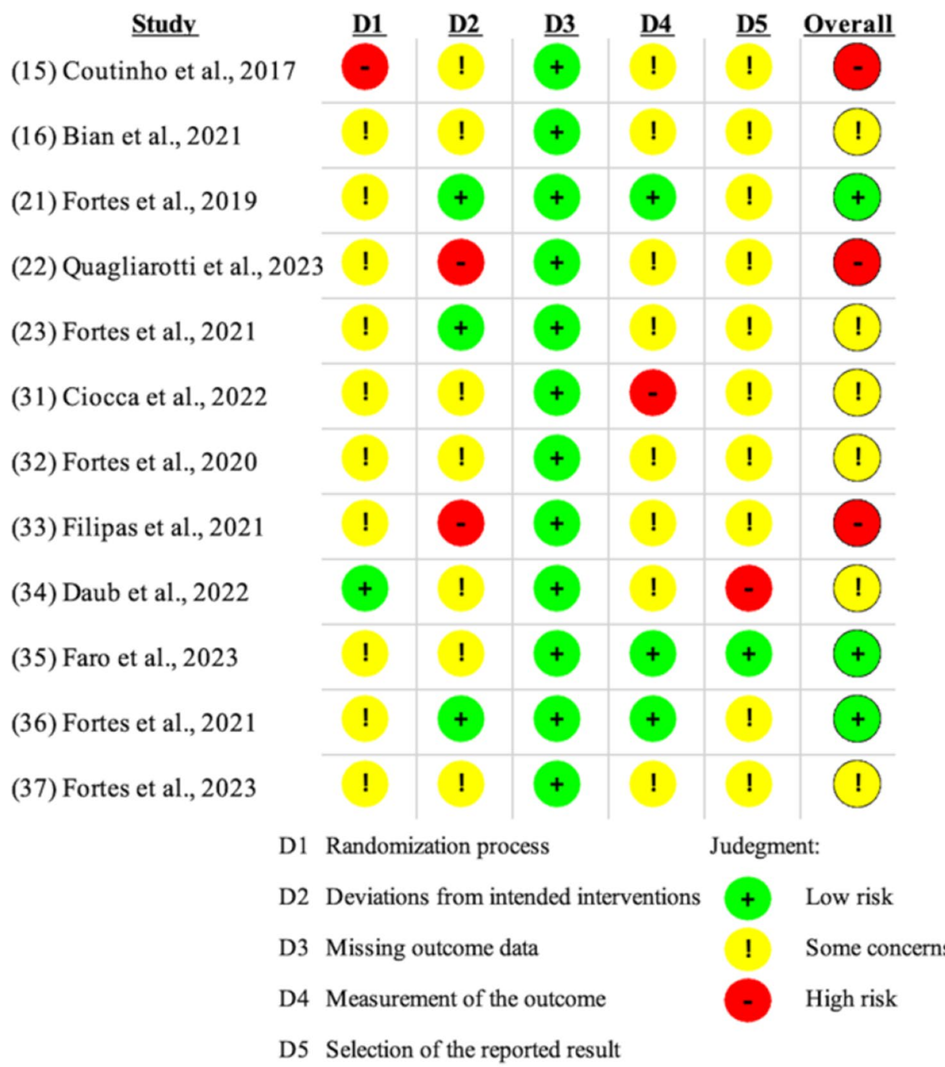

Fig. 2 Risk of bias within the study

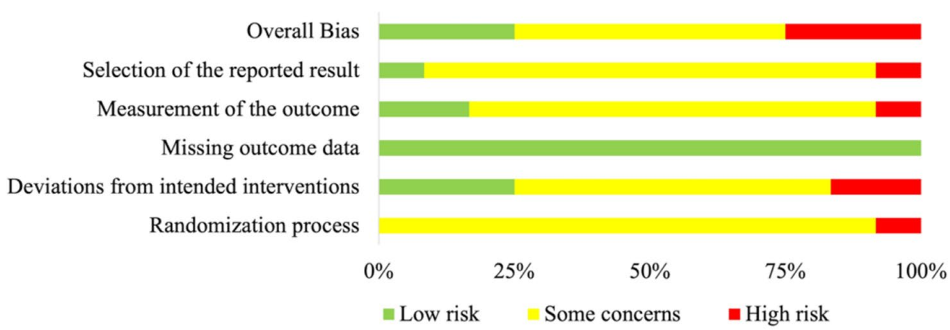

Fig. 3 Risk of bias across studies

the researchers might have already increased, causing concern about the selection of the reported results.

Sports Contexts and Participant Characteristics

Analysis of the sports contexts showed that more ecological inducement of MF mainly occurred in team sports, with soccer [15, 16, 21, 31, 32] being the most involved, followed by basketball [33–35]. Others included sprints [36], freestyle swimming [23], long-distance swimming of the triathlon [22], and boxing [37]. All subsequent sports-specific motor tasks implemented to verify the after effects of induced MF were within the same sports [15, 16, 21–23, 31–37]. Generally, participants were youth (15.9–17.2 years) or adult (20.0–27.9 years) athletes at ≥ Tier 2 level [38] (for details see Table 3).

Mental Fatigue Inducement Task Design

The included MF inducement tasks were classified into two main categories; sports-specific motor tasks [15, 16], and simulated scenarios extracted from athletes' real-life activities. The applied simulated scenarios were further divided into three types; tactical video-based tasks [31, 33, 34], social media use on smartphones [21–23, 32, 36, 37], and sports-themed videogame play [32, 35, 37] (for details see Table 3). Except for the two 20-minute motor tasks with cognitive demands [15, 16] and one 30-minute 60-time tactical clip display with subsequent decision-making answers (i.e., during every 30-second block, 15 s for ticking a movement choice after watching a 6-second video display) [31] that were designed intermittently, the others were all consecutive 15 to 60-minute exposures to tactical videos or social media contents or videogames.

Evaluation of the MF Inducement Effectiveness

Generally, subjective MF on the visual analog scale (MVAS) [15, 16, 22, 23, 33–37] and the reaction performance of short-version computerized Stroop tasks [16, 21–23, 32, 35–37] were broadly used before and after the interventions to check the MF manipulations. Physiological approaches were less commonly employed, with only two studies added to identify MF state by heart rate variability (HRV) indicators [23] and EEG records [35] (see Table 4).

Inducement Effectiveness of Specific Motor Tasks

Twenty minutes of whole-body coordination drill on the agility ladder and the passing skill-based task induced the MF in soccer players, as indicated by elevated MVAS and significant behavioral after effects. The whole-body coordination task led to a decreased ability in spatial exploration and positioning for tactical formation [15] during the small-sided game. The soccer passing skill-based task resulted in lower technical stability and passing accuracy during subsequent LSPT [16].

Inducement Effectiveness of Tactical Video-based Tasks

Tactical video-based tasks showed contradictory effectiveness for the MF inducement. Two of three studies failed to induce MF according to the manipulation check outcomes, only higher mental effort feelings were reported [31, 34]. Further evaluating the subsequent performance, no significant impact on the elite basketball players' shooting performance was shown by watching the tactical video [34]. The passes and the success rate during the small-sided game did not decrease but increased among the national youth soccer players after intermittently watching tactical clips with decision-making answers [31]. Contrarily, watching a similar basketball tactical video induced the MF state of amateur players, with elevated subjective MF and reduced free throw accuracy observed [33].

Inducement Effectiveness of Social Media Use on Smartphones

The executed tasks exhibited inconsistent MF inducement effectiveness. A 45-minute social media exposure failed to elicit MF as indicated by MVAS and the 30-stimuli version Stroop task among amateur triathletes [22]. Additionally, no specific performance or behavioral (i.e., kicking, stroking, breathing) alterations were observed in subsequent endurance swimming [22]. Among the other five studies, three showed significantly higher MVAS after the MF inducement tasks [23, 36, 37]. Simultaneously, the MF inducement effectiveness was verified by increased response time during different short-version (i.e., 30-stimuli [23, 37], and 45-stimuli [36]) Stroop tasks. One study included HRV indicators (interbeat intervals between all successive heartbeats and derivative calculations, for details see Table 4), which showed all declines from initial to post-swimming races regardless of the intervention [23]. The 30-minute inducement tasks hindered amateur boxers' attack and defense decision-making performance in simulated combats [37], and international-level swimmers' speed in simulated 100 and 200 m freestyle swimming races, except the 50-meter race performance [23]. Extending the exposure to 60 min did not impact the simulated 100, 200-meter dash performance in collegiate sprinters [36]. The remaining two studies verified the MF inducement after 30 or 45-minute exposure only by behavioral changes. Professional soccer players showed decreased response speed and accuracy in the 62-stimuli Stroop task and worsened passing decision-making performance during the simulated match [21, 32]. However, the 15-minute exposure did not result in any significant change, thus failing to induce MF [21].

Inducement Effectiveness of Sports-themed Videogame Play

The 30-minute soccer-themed videogame caused a significant decline in response speed and accuracy of the 62-stimuli computerized Stroop task [32]. The induced MF further hindered subsequent passing decision-making performance. Playing the same duration of a boxing-themed videogame, the effective MF inducement was proved by MVAS and the decreased response speed on the 30-stimuli computerized Stroop task [37]. Boxing-specific attack and defense decision-making performance in simulated combats were also reported [37]. Following

Table 3 Overview of mental fatigue-inducing task and control design, representative sports, participants, and subsequent sports-specific tasks

Inducement type	Study	Sports contexts	Participants (Sex, Age, Athletic & competition level)	MF-inducing task			Control	Subsequent sports-specific task
				Task	Content	Feature		
Sports-specific motor task	[15] Coutinho, et al., 2017	Soccer	M = 12 15.9 ± 0.8 yr Highly trained amateur Regional competition	20 min Whole-body coordination motor task	Seven different stepping exercises in a ladder drill while juggling a tennis ball	Intermittent, 4 m practice with 26 m recovery distance, unfamiliar techniques with coordination	20 min Light general aerobic exercises	Soccer SSG
	[16] Bian, et al., 2021	Soccer	M = 15 22.0 ± 2.5 yr Well-trained collegiate Provincial competition	20 min Soccer passing skill-based task	10 times repeated LSPT, receiving, control, dribbling, and passing the ball to targets indicated by randomized verbal order as fast and accurately as possible	Intermittent, 16 passes a block, interval with about 75 s between, 160 times in total, specific skills with decision-making process	1. 20 min computerized Stroop task 2. 20 min motor task of 10 times LSPT with clockwise passing order	Soccer LSPT
Tactical video-based task	[33] Filipas, et al., 2021	Basketball	M = 19 20 ± 3 yr Amateur Regional competition	30 min Basketball tactical video comprehension	Tactical videos created based on the athletic level, after the video, 12 questions were set to check attention	Consecutive, watching and comprehension of basketball-specific tactics	Condition after 5 min standardized warm-up	Basketball 60 Free throws
	[34] Daub, et al., 2022	Basketball	M = 15 20.2 ± 1.2 yr Elite collegiate National top competition	30 min Basketball tactical video watching	Basketball-specific film, the terminology for the tactics of offensive and defensive plays	Consecutive, watching basketball-specific tactics	1. 30 min Computerized Stroop task 2. 30 min Emotionally neutral documentary	Basketball 60 Free throws and 4 min jump shooting on 7 locations
	[31] Ciocca, et al., 2022	Soccer	? = 10 17.2 ± 0.9 yr National National U18 competition	30 min Video-based tactics decision-making	Top-view clips of 30 defense and 30 attack situations from Italian top matches, the static image showed the final scene as a cue, choosing next tactical movement on the paper	Intermittent, 6 s clip, 15 s to tick one of the 3 choices, 4 s black screen and 3 s countdown as the interval	30 min Emotionally neutral documentary	Soccer SSG

Table 3 (continued)

Inducement type	Study	Sports contexts	Participants (Sex, Age, Athletic & competition level)	MF-inducing task			Control	Subsequent sports-specific task
				Task	Content	Feature		
Social media use on smartphone	[21] Fortes, et al., 2019	Soccer	M = 20 24.7 ± 3.6 yr Professional State competition	15/30/45 min Social media apps use on smartphone	Visual content of social media apps (WhatsApp, Facebook, and Instagram)	Consecutive, only using the apps, no speaking	30 min Coaching video documentary	Soccer simulated full-size match
	[23] Fortes, et al., 2021	Freestyle swimming	F = 11 M = 14 20.4 ± 2.06 yr International International and national competitions	30 min Social media apps use on smartphone	Visual content of social media apps (WhatsApp, Facebook, and Instagram)	Consecutive, only using the apps, no speaking	30 min Coaching video documentary	Freestyle swimming simulated 50/100/200 m races
	[36] Fortes, et al., 2021	100/200 m Sprint	M = 16 21.0 ± 0.9 yr Collegiate National university competition	60 min Social media apps use on smartphone	Visual content of social media apps (WhatsApp, Facebook, and Instagram)	Consecutive, only using the apps, write, read, and insert content posts of photos and videos	1. 60 min Computerized Stroop task 2. 60 min Coaching video documentary	Sprints simulated 100/200 m dash
	[22] Quagliarotti, et al., 2023	Triathlon swimming	M = 7 27.9 ± 7.0 yr Tier 2 ?	45 min Smartphone use	Visual content from all installed apps	Consecutive, watching the screen and switching apps, no videos > 2 min and no music	1. 45 min AX-CPT task 2. 45 min Neutral mood documentaries	Front crawl swimming test (6 times 200 m at individual average speed and last 200 m all out)
	[32] Fortes, et al., 2020	Soccer	M = 25 23.4 ± 2.8 yr Professional State competition	30 min Social media apps use on smartphone	Visual content of social media apps (Facebook and Instagram)	Consecutive, using the apps	30 min Advertisement videos	Soccer simulated full-size match
	[37] Fortes, et al., 2023	Boxing	F = 8 M = 13 23.33 ± 3.46 yr Amateur National or regional competition	30 min Social media apps use on smartphone	Visual content of social media apps (WhatsApp, Facebook, and Instagram)	Consecutive, only using the apps, no speaking	30 min Coaching video documentary	Boxing simulated combats (4 rounds of 2 min, 1 min interval)

Table 3 (continued)

Inducement type	Study	Sports contexts	Participants (Sex, Age, Athletic & competition level)	MF-inducing task			Control	Subsequent sports-specific task
				Task	Content	Feature		
Sports-themed videogame play	[32] Fortes, et al., 2020	Soccer	M = 25 23.4 ± 2.8 yr Professional State competition	30 min Soccer-themed videogame play	Soccer-themed videogame, FIFA 2018	Consecutive, playing console, in third-person version	30 min Advertisement videos	Soccer simulated full-size match
	[37] Fortes, et al., 2023	Boxing	F = 8 M = 13 23.33 ± 3.46 yr Amateur National or regional competition	30 min Boxing-themed videogame play	Boxing-themed videogame, Fight Night Round 3	Consecutive, playing console, in first-person version, no speaking	30 min Coaching video documentary	Boxing simulated combats (4 rounds of 2 min, 1 min interval)
	[35] Faro, et al., 2023	Basketball	M = 14 24.3 ± 4.1 yr Tier 3 National competition	60 min Basketball-themed videogame play	Basketball-themed videogame, NBA Live 19	Consecutive, paired by playing level, playing console, in third-person version	60 min Coaching video documentary	Basketball-specific test (6 min visuomotor task with bouncing the ball, 60 times touch 4-color sensors)

Sex represents sex assigned at birth; F, female; M, male; ?, unclear; yr, year; min, minute; s, second; m, meter; SSG, small-sided game; LSPT, Loughborough Soccer Passing Test; AX-CPT, AX-continuous performance task; FIFA, Federation Internationale de Football Association; NBA, The National Basketball Association; App, mobile application

the 60-minute basketball-themed videogame play, national basketball players showed higher MVAS and response time for the 40-stimuli Stroop task. Increased theta waves on the left prefrontal electrode (i.e., Fp1) in EEG records provided further evidence of effective inducement as suggested by previous studies [35, 39, 40]. Videogame-induced MF impaired subsequent reaction performance on a visuomotor test involving basketball-bouncing movements [35].

Discussion

This systematic review aimed to summarize the MF-inducing tasks with greater ecological validity with regard to sports training and performance and evaluate their inducement effectiveness. The included sports-specific motor tasks and simulated athletes' real-life scenarios addressed the primary consideration of ecological validity by incorporating representative sports elements or simulating daily scenarios that athletes face in real-world settings into task designs. However, the review also highlighted considerable variability in the effectiveness of these specific approaches, and nuances to consider for the application of representative MF-inducing tasks.

Stance on Ecological Validity of MF Inducement in Sports

Ecological validity is mainly used to discuss whether experimental research resembles and generalizes to the 'real world' [41]. During the progress of studies inducing MF in sports, researchers adopted this term (i.e., 'limited' ecological validity) [10, 12, 13] to critically evaluate previous fundamental studies, especially for the purpose of translating laboratory-based evidence into practice. However, it is unrealistic for ecological validity to imply that research should always occur during open analysis of performance, since control is necessary for participants to exhibit truthful behaviors [42]. Given the importance of maintaining the experimental control, first manipulating cognitive load by employing an isolated, static task in the fundamental studies to induce MF, holds scientific rigor. Therefore, based on these perspectives, the current systematic review does not take an adversarial position towards previous traditional research, nor does it advocate that an event occurring in real life (e.g., transcribing task [43–45]) inherently results in high ecological validity to a particular sports environment. Considering the challenges in determining the specific nature of the 'ecologically valid standard', the inclusion criteria were established to focus on dynamic motor tasks that involve sports-specific elements or applications of simulated cognitive-demanding scenarios encountered in athletes' real lives.

Effectiveness of Different MF Inducement Tasks

Sports-specific Motor Tasks

The review identified two primary approaches: whole-body coordination and soccer passing skill-based tasks. Both methods showed effectiveness in inducing MF in soccer players after 20 min. The whole-body

Table 4 Evaluation of the mental fatigue inducement effectiveness of different tasks

Inducement Type	Study	MF-inducing task	Evaluation of MF inducement effectiveness				Effectiveness Conclusion
			Subjective marker	behavioral markers		(Neuro)-physiological marker	
				Post-inducement manipulation check	Subsequent athletic performance		
Sports-specific motor task	[15] Coutinho, et al., 2017	20 min Whole-body coordination motor task	MVAS +	/	Tactical-related positioning performance - (SSG contraction speed -, lateral synchronization time -)	/	Y
	[16] Bian, et al., 2021	20 min Soccer passing skill-based task	MVAS +	Cognitive performance of 3 min computerized Stroop task X	Technical performance - (LSPT passing accuracy -, technical stability -)	/	Y
Tactical video-based task	[33] Filipas, et al., 2021	30 min Basketball tactical video comprehension	MVAS +	/	Technical performance - (shooting accuracy -)	/	Y
	[34] Daub, et al., 2022	30 min Basketball tactical video watching	MVAS X (VAS-mental effort +)	/	Technical performance X (shots made, shots missed X)	/	N
	[31] Ciocca, et al., 2022	30 min Video-based tactics decision-making	/ (VAS-mental effort +)	/	Physical performance X Technical performance + (passes, successful passes +)	/	N
Social media use on smartphone	[21] Fortes, et al., 2019	15/30/45 min Social media apps use on smartphone	/	Cognitive performance of 62 stimuli computerized Stroop task - (after 30/45 min tasks, response speed -, accuracy -)	Passing decision-making performance - (performance after 30/45 min task -) Technical performance X (passes X)	/	30, 45 min Y 15 min N
	[23] Fortes, et al., 2021	30 min Social media apps use on smartphone	MVAS +	Cognitive performance of 30 stimuli computerized Stroop task - (response speed -)	Swimming performance – (100/200 m speed -, 50 m speed X)	HRV: R-R interval, SDNN, RMSSD, pNN50 X	Y
	[36] Fortes, et al., 2021	60 min Social media apps use on smartphone	MVAS +	Cognitive performance of 45 stimuli computerized Stroop task - (response speed -)	100/200 m dash performance X	/	Y
	[22] Quagliarotti, et al., 2023	45 min Smartphone use	MVAS X	Cognitive performance of 30 stimuli computerized Stroop task X	Swimming performance X biomechanical variables X	/	N
	[32] Fortes, et al., 2020	30 min Social media apps use on smartphone	/	Cognitive performance of 62 stimuli computerized Stroop task - (response speed -, accuracy -)	Passing decision-making performance - Technical performance X (passes X)	/	Y
	[37] Fortes, et al., 2023	30 min Social media apps use on smartphone	MVAS +	Cognitive performance of 30 stimuli computerized Stroop task - (response speed -)	Boxing decision-making performance - (attack and defense decision-making -)	/	Y

Table 4 (continued)

Inducement Type	Study	MF-inducing task	Evaluation of MF inducement effectiveness				Effectiveness Conclusion
			Subjective marker	behavioral markers		(Neuro)-physiological marker	
				Post-inducement manipulation check	Subsequent athletic performance		
Sports-themed videogame play	[32] Fortes, et al., 2020	30 min Soccer-themed videogame play	/	Cognitive performance of 62 stimuli computerized Stroop task - (response speed -, accuracy -)	Passing decision-making performance - Technical performance X (passes X)	/	Y
	[37] Fortes, et al., 2023	30 min Boxing-themed videogame play	MVAS +	Cognitive performance of 30 stimuli computerized Stroop task - (response speed -)	Boxing decision-making performance - (attack and defense decision-making -)	/	Y
	[35] Faro, et al., 2023	60 min Basketball-themed videogame play	MVAS +	Cognitive performance of 40 stimuli computerized Stroop task - (response speed -)	Visuomotor performance - (speed and accuracy -)	EEG: theta wave on Fp1 +	Y

+, significantly increased; -, significantly decreased; X, unchanged; /, unused; Y, successfully induced; N, failed to induce; VAS, visual analog scale; MVAS, subjective mental fatigue on the visual analog scale; SSG, small-sided game; LSPT, Loughborough soccer passing test; min, minute; m, meter; HRV, heart rate variability; R-R interval, interbeat intervals between all successive heartbeats; SDNN, the standard deviation of all interbeat intervals from which artifacts have been removed; pNN50, the consecutive percentage of R-R interval differences greater than 50 ms; RMSSD, the difference of the quadratic mean of the successive R-R normal intervals; EEG, electroencephalogram; Fp1, left prefrontal electrode

coordination task emphasized motor coordination under spatial pressure [15], while the soccer passing skill-based task focused on accurate decision-making and movement executions under time pressure [16]. The common feature of the two tasks is adding the active processing of environmental information from the field into the serial movement combination. The dynamic task mode requires selective and sustained attention [46], as well as challenges players' ability to inhibit automatic response, initiated action, or inappropriate behavior, or compete with distracting stimuli that may compromise performance [47]. Incorporation of technical movements and cognitive requirements may represent part of the elements from pre-match warm-up protocols, gaining ecological validity of such MF inducement task designs for performance after effects studies.

Simulated Scenarios in Athletes' Real-Life Settings

Unlike motor task design simulating soccer-specific preparatory training or pre-match warm-up sessions, the included studies predominantly isolated athletes to replicate their prolonged use of digital devices (e.g., smartphones, tablets) in real-life settings. These experimental designs are particularly relevant when controlling exposure to social media, videogame, or tactical video content (e.g., tactics session, team talk) occurring prior to daily training and competitions.

The use of sports-themed (i.e., soccer, boxing, and basketball) videogames to induce MF in athletes has shown consistent effectiveness [32, 35, 37]. These interactive and immersive videogames recreated authentic match environments and required athletes to use controllers to execute movement sequences, thereby providing an ecological and engaging experience that simulates the cognitive demands of actual competitions [35]. Despite the largely seated position, the high-level attention required, rapid processing of visual information from the dynamic virtual environment, decision-making under time pressure, the need for fine-motor control of fingers and hand-eye coordination, all contribute to cognitive load and subsequent potential for inducement of MF [48–50].

The consecutive use of social media on smartphones induced MF in all but one included study. Generally, a minimum of 30 min of exposure to social media content was effective in inducing MF. The prolonged gazing and interactive activities on the screen require constant attention and information processing [51, 52]. Users frequently switch between different types of texts, images, and videos, which demands continuous cognitive engagement and can lead to cognition overload [53, 54]. This multitasking process and response to a high volume of information can exhaust attentional resources [55] and hinder executive function [56], leading to MF [57]. In addition, daily social media use often involves emotional engagement, as users interact with content that can elicit a wide range of emotions from positive to negative. The emotional regulation required to process these interactions could further contribute to MF [58, 59]. However, 45-minute smartphone content exposure among amateur triathletes did not induce MF [22]. Participants were allowed to switch between any apps installed on the smartphone. The flexible and relaxed nature likely diluted cognitive load [60] compared to more immersive and forced social media interaction tasks previously employed. Because social media use on smartphones in daily life may be in a more relaxed manner, as opposed to typically blocked, forced laboratory settings with MF inducement purposes, this should be considered when transferring such applications into practice. To standardize such task design and enhance cross-study comparability, researchers should prioritize the quantification and control of trial/stimulus dosage and type (e.g., specific social media content and interaction frequency). Due to the largely static nature, future studies with this theme may benefit from utilizing (neuro)physiological markers (e.g., functional near-infrared spectroscopy [f-NIRS] and Eye-tracker) throughout social media use. Furthermore, in this study, a 15-minute warm-up session was set between the smartphone exposure and subsequent swimming races. Low-intensity warm-up activities can increase arousal and counteract the impacts of MF by boosting dopamine levels and overall alertness [61, 62], potentially countering any social media inducement effects. It also suggests that more research should focus on the arrangement and optimal combinations of pre-match activities in a limited time window, an area of interest for athletes and sports practitioners to better manage and prevent the MF.

Two studies involving watching basketball tactical videos [33, 34] yielded contrasting effectiveness on MF inducement. The study that required participants to watch basketball tactical videos and subsequently answer 12 questions based on the content successfully induced MF [33]. Similar to the studies in academic settings, this active engagement and cognitive demands involved in the theoretical learning process and prolonged attention maintenance likely contributed to the higher level of MF [63, 64]. Contrarily, the other study with solely passive exposure to a tactics terminology film did not effectively induce MF. Although the national-level basketball players self-reported more mental effort after the task, their shooting performance and MF values showed no significant changes [34]. This is consistent with the function of emotionally neutral documentary viewing tasks that are widely used as a control due to the low level of cognitive engagement [65, 66]. Additionally, the soccer tactical video-based task involving intermittent match records watching and related decision-making answers failed to induce MF [31]. Despite the active engagement in skills decision-making related to actual soccer scenarios, the low stimuli frequency (i.e., one time in the 30-second block), combined with the fixed response mode of three known choices under sufficient time, might not reach the sustained, intense cognitive load necessary to induce significant MF [13, 67].

Variability in Inducement Effectiveness Within One Type of Task

It is evident that dynamic, structured tasks with intense cognitive demands and prolonged, active engagement are generally effective in inducing MF in sports contexts. Meanwhile, the observed inconsistency in inducement effectiveness within one type of task indicates the variability in the design, application, and response of MF-inducing tasks.

Variable effectiveness in MF inducement can be attributed to diversity in participants' features such as age, athletic level, and prior training and competition experience [28, 68]. When cross-checking two similar tactical video-based tasks, the one applied to elite basketball players competing at the highest national league showed ineffective inducement [34], while the other induced MF successfully in regional amateurs [33]. Consistently, more experienced athletes were found less susceptible [45, 69, 70] to induced MF. Meanwhile, different sports contexts impose unique cognitive and physical demands, which may shape different natures of fatigue, and in turn, change the logic of ecological MF inducement. Ecologically valid MF-inducing task design requires a better understanding of the contextual differences and representative elements in particular sports contexts, as well as the real-life causations of MF in particular athletes [71].

The duration of exposure to MF-inducing tasks played an important role. Van Cutsem et al. (2017) proposed a cut-off value of 30 min that aligns with the minimal cortical activity time required to induce MF [6]. Direct comparisons in one study showed that a shorter 15 min of smartphone use failed to induce significant MF, whereas 45 min of longer use could induce MF but caused no more detrimental after effects [21]. However, two soccer-specific motor tasks could effectively induce MF in 20 min [15, 16]. The dynamic, dual-task design with movement execution and extra cognitive demands from environmental cues might account for the successful inducement in a shorter duration than virtual tasks [72]. The application for MF inducement needs to consider manipulating the task variability in duration and intensity, increasing contextual interference [13] to mimic athletes' cognitive activities. Interestingly, Zeuwts et al. (2021) investigated the Stroop-task-induced MF in young cyclists with an innovative virtual reality simulator to mimic traffic situations [18], a practical design that inspires further reappearance in sports scenarios.

The variability in MF inducement effectiveness also stems from differences in how MF is measured and verified through manipulation checks and subsequent behavioral assessments. Studies mainly utilizing subjective indicators such as the MVAS in combination with objective cognitive performance tests like the short-version Stroop task tend to provide more robust evidence of MF

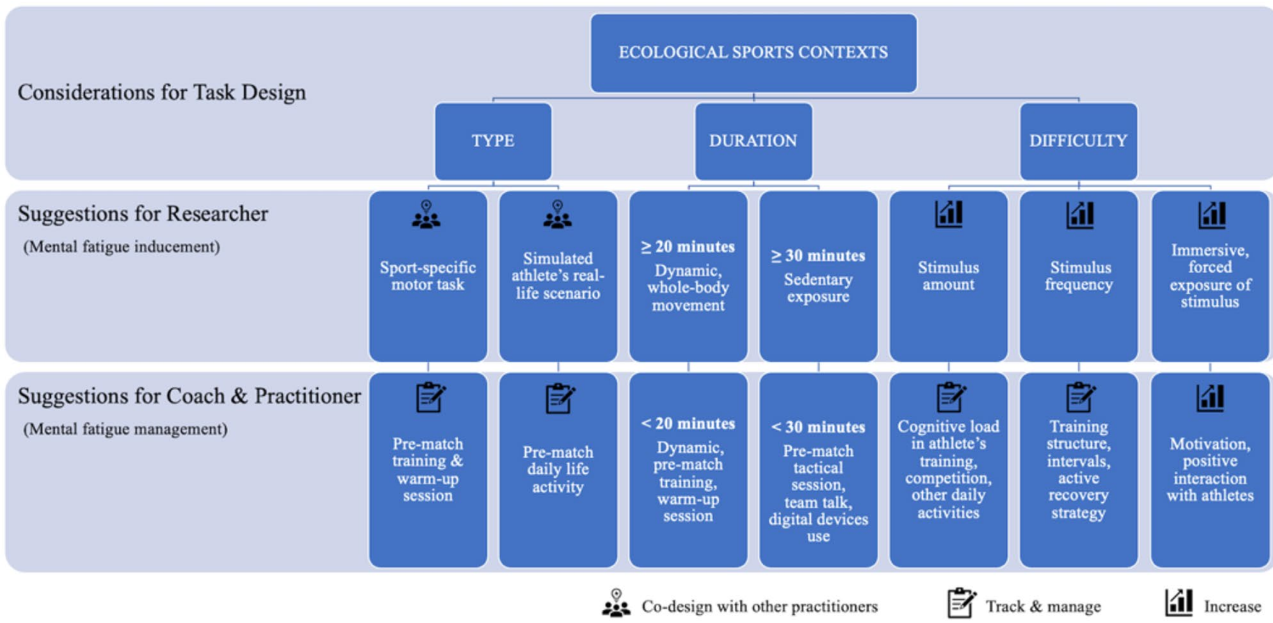

Fig. 4 Considerations and practical suggestions

inducement [73, 74]. However, discrepancies arise when only a single measure is used or when the selected assessment methods are not sensitive enough to detect potential changes.

Limitations

Although the present review assessed both manipulation checks and the behavioral after effects of potentially induced MF on subsequent sports-specific performance, the inherent heterogeneity in detailed task designs, sports contexts, and athletes' characteristics, combined with the limited number of studies, challenged cross-comparisons within specific inducement approaches. As indicated by the risk of bias evaluation, randomization of task allocation and single-blind design for athletes was commonly guaranteed, but not for the investigators. There is a possibility that the observer expectancy effect [75] could interfere with the effectiveness interpretation. Furthermore, the self-reported MVAS was most utilized to verify the MF inducement. However, as subjective feelings inherently synthesize multifactorial information (e.g., physiological, cognitive, and emotional) inputs, the assessment tool should be distinguished from, rather than be interchangeable with, objective measures [76]. In some studies, the significant elevation of MVAS observed may also be partially due to the acquiescence bias [13], as well as influenced by the clear distinction between a cognitively demanding task and casually watching the documentary, where the MF-inducing purpose could be easily detected. When interpreting and transferring the conclusions, standardization issues, contextual differences, and evidence bias should be considered.

Implications for Future Research and Practice

Future research should focus on enhancing the ecological validity of MF-inducing tasks by using sports-specific motor tasks in open environments or athletes' real-life scenarios. Combining qualitative and quantitative approaches will help better understand MF contributors and real-life causations in specific sports contexts, leading to MF inducement tasks that more closely relate to the demands of training and competition. Incorporating advanced technologies like virtual and augmented reality may open up the opportunity to create more precise simulations for MF inducement. Additionally, more balanced studies across diverse participants and sports contexts are needed to broaden MF applications. Integrating multifaceted indicators, including subjective monitoring, behavioral tasks, and (neuro)physiological assessments, throughout the inducement process will improve the accuracy of MF evaluation. As illustrated in Fig. 4, the ineffective inducement task design also reflects that athletes and sports practitioners should be mindful of managing the duration, content, and engagement forms of pre-match activities, in case of inducing or aggravating MF which may impair performance.

Conclusion

This systematic review evaluated the MF inducement methodologies in sports contexts with a particular focus on ecological validity and representative design. The inducement effectiveness varied within the task type, suggesting the need for tailored design and standardized evaluation to specific contexts. Findings indicated that 20-minute sports-specific motor tasks with cognitive demands and most of the 30-minute simulated real-life scenarios successfully induced MF in different athletes. Where ineffective inducement was observed, this was due to contributing factors of shorter duration, passive engagement with sparse cognitive demands, or conducted on less susceptible participants. Athletes and sports practitioners should carefully manage the modality and content of the pre-match activities to prevent inducing or aggravating MF. Future research should refine and co-design the MF-inducing task with practitioners based on multifaceted MF evidence in the laboratory and real-life settings, create immersive scenarios that can better replicate the inducement process in specific contexts, and improve measurement tools, which will provide comprehensive evaluation and verification of the MF inducement.

Abbreviations

MF	Mental fatigue
PICOS	Population, intervention, comparison, outcomes, and study design
RoB 2	Revised Cochrane risk of bias tool for randomized trials
LSPT	Loughborough soccer passing test
MVAS	Subjective mental fatigue on visual analog scale
SSG	Small-sided game
EEG	Electroencephalogram
HRV	Heart rate variability
App	Mobile application

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Author Contributions
CB, BR, and SR conceptualized the topic and finalized the detailed search strategy. CB, AM, and EL performed the primary literature search and full-text screening. Data synthesis and presentation were conducted by CB and AM. CB wrote the first draft of the manuscript. ŠB, SR, JH, and KDP later helped adjust the general construction, modify the main content, and polish the sentences. CB, BR, and SR updated and finalized the manuscript. All authors read, revised, and approved the final manuscript.

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Data Availability
All data generated or analyzed during this study are included in this published article.

Declarations

Ethics Approval and Consent to Participate
Chao Bian, Suzanna Russell, Ana Mali, Elke Lathouwers, Kevin De Pauw, Jelle Habay, Špela Bogataj, and Bart Roelands declare that the systematic review complies with all ethical standards. No participants were recruilted for the present study, so no consent for participation needed to be collected.

Consent for Publication
Not applicable.

Competing Interests
Chao Bian, Suzanna Russell, Ana Mali, Elke Lathouwers, Kevin De Pauw, Jelle Habay, Špela Bogataj, and Bart Roelands have no competing interests relevant to the content of this review.

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