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Effects of physical and mental fatigue on competitive fencing performance: a systematic review

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ABSTRACT

Fencing is an open-skill combat sport in which rapid perception, decision-making, and precise motor execution are performed under intermittent high-intensity demands. Fatigue may therefore affect performance through both neuromuscular and cognitive pathways. This systematic review examined how physical and mental fatigue manifest in competitive fencing, how fatigue influences performance, and which countermeasures have been investigated. Following PRISMA 2020, Scopus, PubMed, and ScienceDirect were searched, yielding 295 records. After removal of 15 duplicates and screening, 44 reports were assessed for eligibility and 14 primary empirical studies were included. The included evidence comprised four randomized studies, six non-randomized quantitative studies, three quantitative descriptive studies, and one qualitative study. MMAT quality scores ranged from 3.5 to 5.0/5.0; 11 studies were rated high and three medium. Because of substantial heterogeneity in study design, fatigue-induction protocols, and outcome measures, findings were synthesized narratively using thematic synthesis rather than meta-analysis. Across the included evidence, simulated or competitive fencing was associated with increasing perceived and/or mental fatigue and with modest neuromuscular fatigability, while reaction time showed the most consistent performance decrement. Higher expertise appeared to buffer movement-precision loss. Nutritional, thermal, and cognitive countermeasures showed preliminary benefits, but objective fencing-performance effects remain uncertain. The evidence supports integrated monitoring of physical and mental fatigue and larger, adequately powered, ecologically valid trials.

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Introduction

Fencing is an open-skill combat sport performed with three weapons—épée, foil, and sabre—in which athletes must perceive an opponent's actions, select an appropriate response, and execute accurate movements within very short time windows. Competitive bouts combine brief, high-intensity efforts with repeated recovery periods and sustained perceptual-cognitive demands (Roi & Bianchedi, 2008; Turner et al., 2014, 2017a; Yang et al., 2022). Consequently, factors that slow reaction time, impair decision-making, or reduce movement precision can directly threaten competitive performance.

Fatigue in fencing should be considered multidimensional rather than exclusively physiological. Neuromuscular fatigue reflects a reduced ability of the neuromuscular system to produce or sustain force after exercise, whereas mental fatigue is associated with prolonged cognitive effort and altered attention, effort perception, and response speed (Xiao et al., 2026; Xu et al., 2026; Hassar et al., 2026; Dirik & Özpolat, 2026). The intermittent structure of fencing makes it particularly relevant to examine whether neuromuscular fatigability and cognitive fatigue develop concurrently and whether one domain can be compensated for by resources from the other.

Previous fencing research has established substantial physiological demands, including elevated heart rate and metabolic responses, while elite performers also demonstrate strong endurance, explosive power, and perceptual-cognitive abilities (Tsolakis et al., 2010, 2011; Turner et al., 2013; Chan et al., 2011). Session rating of perceived exertion provides an ecologically relevant indicator of internal load (Turner et al., 2017b). More recent work has expanded the field toward real-world mental-fatigue monitoring and competition-specific cognitive demands, suggesting that mental fatigue can rise across training and competition and may coincide with slower psychomotor responses (Bian et al., 2025a, 2025b, 2025c).

Despite this progress, an important evidence gap remains. Physical and mental fatigue have often been measured separately, with different fatigue-induction protocols and outcome batteries, limiting direct comparison across studies. The available fencing literature is also dominated by small samples, and relatively few studies assess neuromuscular and cognitive fatigue concurrently under ecologically representative competitive conditions. This fragmentation makes it difficult to determine which aspects of fatigue most consistently affect fencing performance and which countermeasures have evidence beyond changes in perceived fatigue or physiological load. A systematic review is therefore justified to integrate the heterogeneous evidence rather than assume that findings from one fatigue domain generalize to the other.

Accordingly, this review used a systematic literature review design because the research questions concern a heterogeneous body of empirical studies spanning experimental, observational, and qualitative designs. A systematic review allows the evidence to be identified using predefined eligibility criteria, appraised using a design-appropriate quality framework, and synthesized transparently without imposing an inappropriate pooled effect estimate when outcomes are not sufficiently comparable. The objectives were to: (1) characterize the manifestation and development of physical and mental fatigue in competitive fencers; (2) determine how fatigue affects fencing-relevant performance outcomes, particularly reaction time, movement precision, and cognitive-attentional function; and (3) identify interventions or strategies that have been investigated to mitigate fatigue-related performance decline. The review questions were:

RQ1: How do physical (neuromuscular) and mental (cognitive) fatigue manifest and develop during training and competition in competitive fencers?

RQ2: What are the effects of fatigue on fencing-specific performance outcomes, including reaction time, movement precision, and cognitive-attentional function?

RQ3: Which interventions or strategies have been investigated to mitigate fatigue or attenuate fatigue-related performance decline in fencers?

This review therefore integrates the physical, mental, and combined fatigue evidence in fencing, compares the consistency of performance effects across study designs, and identifies methodological priorities for monitoring and intervention research.

Method

Research design and framework

The review approach of this work was primarily of a systematic literature review nature to transparently identify, evaluate and combine results from the available primary studies on a well-formulated question minimising selection and reporting bias (Tranfield et al., 2003; Liberati et al., 2009). For reporting and carrying out the work, we used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 (Page et al., 2021; Moher et al., 2009). The review protocol containing the research questions, search strategy, inclusion criteria, and data extraction form was planned beforehand and used in a consistent manner.

Search strategy

Table 1. PICOS framework used to structure the search strategy.

PICOS element	Operationalisation in this review
Population (P)	Competitive fencers (épée, foil, sabre; able-bodied and wheelchair; youth to elite)
Intervention / Interest (I)	Physical (neuromuscular) and/or mental (cognitive) fatigue induced by training or competition, and countermeasures targeting fatigue

PICOS element	Operationalisation in this review
Comparison (C)	Rested versus fatigued states, experimental versus control conditions, or across competitive phases (where applicable)
Outcome (O)	Fencing-specific and general performance markers: reaction time, movement precision/accuracy, neuromuscular function, physiological load, and subjective fatigue
Study design (S)	Empirical primary studies (experimental, quasi-experimental, observational, and survey designs)

The search strategy was translated to the syntax of each database and applied to title, abstract, and keyword fields where supported. Wildcards were used to capture morphological variants (e.g., fenc* and fatigu*). The search was intentionally broad at the population and fatigue levels and was refined with performance-related terms because the word "foil" generated substantial non-sporting engineering/materials-science retrievals. The complete database-specific strings should be retained in the review record to support exact replication.

("fenc*" OR "épée" OR "epee" OR "foil*" OR "sabre" OR "saber") AND ("fatigue" OR "fatigability" OR "mental fatigue" OR "cognitive fatigue" OR "neuromuscular fatigue") AND ("performance" OR "reaction time" OR "precision" OR "accuracy" OR "attention" OR "decision*")

The string was piloted iteratively. An initial version without the outcome cluster produced many non-sporting records containing "foil"; adding performance terms and weapon-specific synonyms increased precision while retaining fencing-related fatigue studies.

Database and information sources

Three databases were searched: Scopus, PubMed, and ScienceDirect. Scopus was selected for broad multidisciplinary coverage, PubMed for biomedical and exercise-physiology literature, and ScienceDirect for additional full-text coverage in sport-science and related disciplines. The three-database strategy was feasible within the available review workflow, but it does not provide the coverage of a database set that also includes SPORTDiscus or Web of Science. No grey-literature database search, manual journal search, backward citation chasing, or forward citation tracking was undertaken; this is now explicitly acknowledged as a limitation because relevant studies may therefore have been missed. Searches were restricted to English-language peer-reviewed records with retrievable full text.

Eligibility criteria

Table 2. Inclusion and exclusion criteria.

Criterion	Inclusion	Exclusion
Language	Published in English	Not available in English
Document type	Peer-reviewed journal article or review	Conference paper, book chapter, editorial, or note
Population	Competitive fencers of any weapon or level	Non-fencers or mixed samples where fencers cannot be isolated
Focus	Directly examines physical and/or mental fatigue and a performance-related outcome in fencing	Tangential mention of fatigue only, or non-fatigue focus
Data	Reports primary empirical data	No primary data (e.g., commentary, protocol only)
Accessibility	Full text retrievable	Full text not retrievable

Study selection process

Selection proceeded in two stages. Records retrieved from the three databases were pooled and screened for duplicates. The remaining records underwent title-and-abstract screening against the predefined eligibility criteria, followed by full-text assessment of potentially eligible reports. The workflow yielded 295 records, 15 duplicates, 280 title-and-abstract records screened, 236 records excluded at screening, and 44 reports assessed at full text; 30 were excluded at full text and 14 primary empirical studies entered the synthesis. Study counts are now reconciled with Figure 1. Inter-rater agreement was not prospectively recorded in the retained review workflow, so a valid Cohen's kappa cannot be reconstructed retrospectively; this limitation is reported rather than replaced with an estimated statistic.

Quality assessment

The methodological quality of each included study was appraised using the Mixed Methods Appraisal Tool (MMAT), version 2018 (Hong et al., 2018). The appropriate five-item MMAT checklist was selected according to study design. Each criterion was coded as met (1), partially met (0.5), or not met (0), producing a descriptive score from 0 to 5. Consistent with the MMAT framework, scores were not used as an exclusion threshold. Across the 14 included studies, scores ranged from 3.5 to 5.0; 11 studies were classified as high methodological

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quality and three as medium. Inter-rater agreement data for the original appraisal were not retained and therefore no reliability coefficient is reported.

Table 3. Methodological quality appraisal using the MMAT (version 2018).

Author(s), Year	Design	S1	S2	S3	S4	S5	Total	Rating
Turner et al. (2017a)	Quant. descriptive	1	1	1	0.5	1	4.5	High
Bian et al. (2025a)	Quant. non-random.	1	1	1	1	1	5.0	High
Witkowski et al. (2019)	Quant. non-random.	1	1	0.5	1	1	4.5	High
Yang et al. (2022)	Quant. descriptive	1	1	1	0.5	1	4.5	High
Bian et al. (2025b)	Qualitative	1	1	1	0.5	1	4.5	High
Obmiński et al. (1998)	Quant. descriptive	1	0.5	0.5	0.5	1	3.5	Medium
Devienne et al. (2000)	Quant. non-random.	1	0.5	0.5	1	0.5	3.5	Medium
Bian et al. (2025c)	Quant. non-random.	1	1	1	1	1	5.0	High
Varesco et al. (2023)	Quant. non-random.	1	1	1	1	1	5.0	High
Varesco et al. (2025)	Quant. randomized	1	1	0.5	1	1	4.5	High
Barañano-Alcaide et al. (2025)	Quant. non-random.	1	1	1	0.5	1	4.5	High
Rowlatt et al. (2017)	Quant. randomized	1	1	1	1	0.5	4.5	High
Bottoms et al. (2013)	Quant. randomized	1	1	1	0.5	1	4.5	High
Morris & Glaister (2024)	Quant. randomized	1	1	0.5	0.5	0.5	3.5	Medium

Note. S1–S5 denote the five MMAT criteria appropriate to each study's design category. Total scores are on a 0–5 scale; Rating: High (≥4), Medium (3–3.5), Low (<3).

Data extraction procedure

A standardised extraction template captured authors and year, sample size, sex, competitive level, weapon(s), study design, fatigue-induction stimulus or intervention, outcome measures, and principal findings. When a field was not reported in the source record, it was recorded as not reported rather than inferred. Data extraction was undertaken as a structured review workflow; because an independent duplicate-extraction audit was not prospectively recorded, inter-rater reliability cannot be calculated retrospectively and is identified as a methodological limitation.

Network and bibliometric analysis

A formal co-authorship or keyword co-occurrence network analysis was not performed, given the modest number of included studies. Instead, descriptive bibliometric mapping of the evidence base was undertaken, including the temporal distribution of included studies (Figure 2) and the distribution of studies across research questions, fatigue domains, and measurement categories (Figures 3 and 4).

Data analysis and synthesis

Because the included studies differed substantially in design, fatigue-induction protocol, population, weapon, and outcome definition, quantitative meta-analysis was not considered appropriate. Findings were synthesized narratively using thematic synthesis (Thomas & Harden, 2008). Extracted results were organized under the three research questions and then compared for convergence, divergence, direction of effects, and methodological limitations. This approach was selected to avoid treating non-equivalent outcomes as if they represented a common estimand.

Reporting and documentation

The review was conducted and reported in accordance with PRISMA 2020 (Page et al., 2021). The final manuscript reports the 295 identified records, 15 duplicates removed, 280 screened records, 44 full-text reports assessed, 30 full-text exclusions, and 14 included studies consistently across the text and Figure 1. The search was limited to publications available in English and indexed in Scopus, PubMed, or ScienceDirect; the exact database execution date was not retained in the source workflow and is therefore not stated as an invented date.

Results and Discussions

Study selection results

A total of 295 database records were identified (Scopus n = 124; PubMed n = 71; ScienceDirect n = 100). After 15 duplicates were removed, 280 records underwent title-and-abstract screening and 236 were excluded. Forty-four reports were assessed in full text; 30 were excluded because they did not address fatigue or performance in fencing (n = 13), involved a non-fencing population or different discipline (n = 8), did not report primary empirical fatigue data (n = 6), or did not have retrievable full text (n = 3). Fourteen primary empirical studies were therefore included in the final synthesis. These figures correspond to Figure 1.

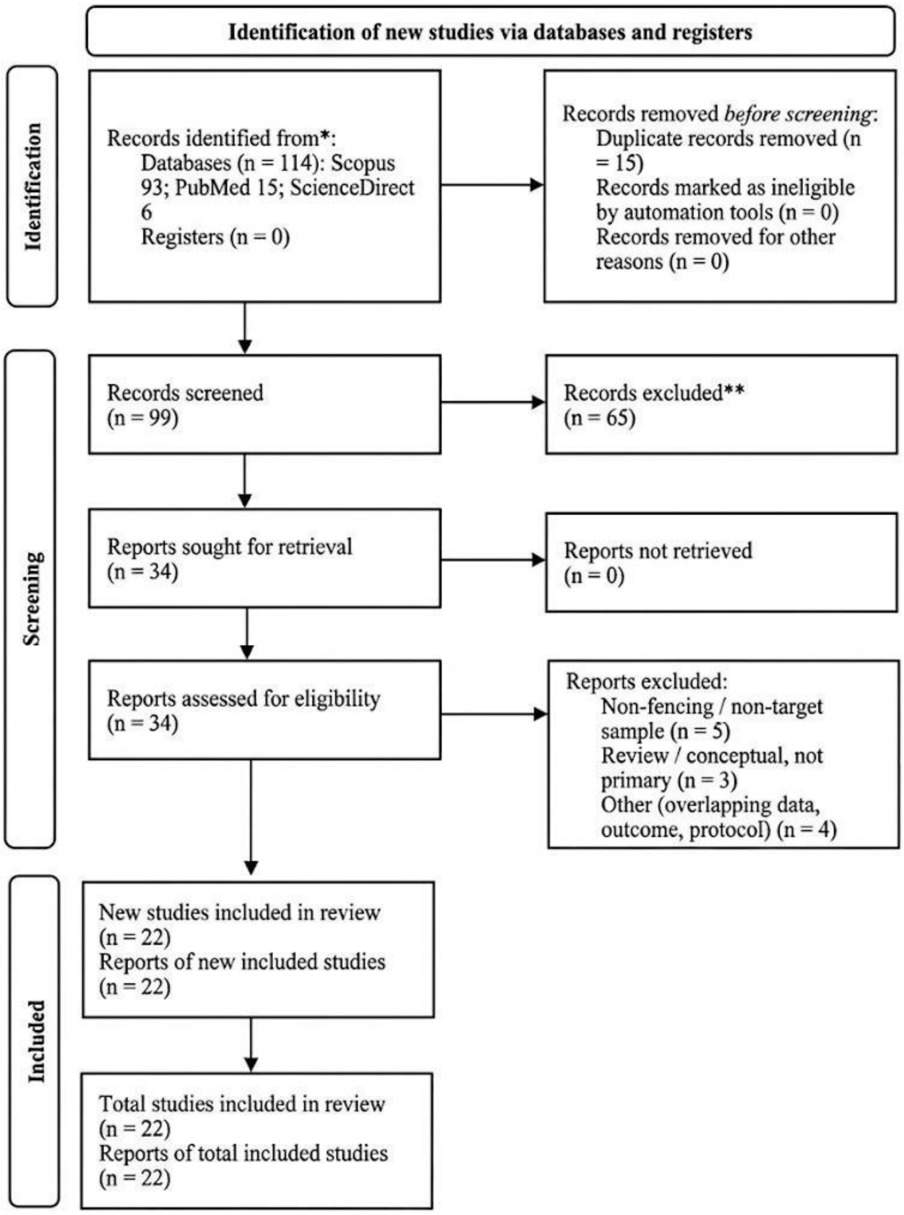

Figure 1. PRISMA 2020 flow diagram of study identification and selection. Record counts are drawn from the three databases searched; duplicate and exclusion counts follow the two-stage screening process. Adapted from the PRISMA 2020 statement (Page et al., 2021; Moher et al., 2009).

Descriptive characteristics of included studies

Fourteen empirical studies were included, published from 1998 to 2025, with 11 published from 2017 onward and five in 2025. Study samples were generally small; among studies that explicitly reported a participant count in the extracted record, sample sizes ranged from 6 to 48, while two studies did not provide a clear sample size in the retained extraction. The corpus covered all three fencing weapons but was weighted toward elite or national-level fencers. Methodological quality was high in 11 studies and medium in three (MMAT; Table 3).

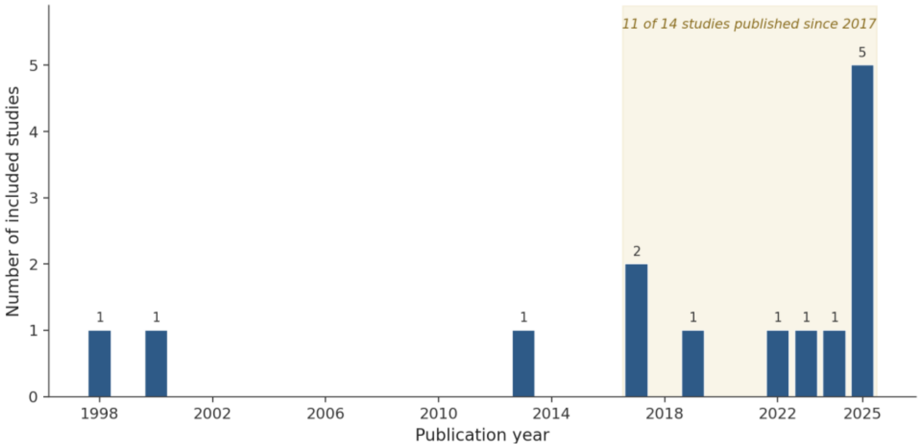

Figure 2. Temporal distribution of the 14 included studies. Publication activity is heavily weighted toward the last decade, with 2025 the most productive year in the sample.

Table 4. Summary characteristics of the included studies.

Title	Author(s), Year	Sample & level	Key findings
Concentrations of cortisol, testosterone and lactate, and power output in repeated, supramaximal exercise in elite fencers	Obmiński et al. (1998)	45 male elite fencers	Two 10-s supramaximal bouts increased power and testosterone (~9%) with low, undifferentiated cortisol; the protocol did not induce marked fatigue and may serve as a pre-competition warm-up.
Local muscular fatigue and attentional processes in a fencing task	Devienne et al. (2000)	9 men (choice-RT fencing task)	Submaximal isometric contractions did not reliably alter premotor or motor time or attentional processes in a choice-reaction fencing task; effects were obscured by inter-individual variability and an insufficiently fatiguing stimulus.
The effect of caffeine ingestion on skill maintenance and fatigue in epee fencers	Bottoms et al. (2013)	11 competitive fencers (crossover)	Caffeine (3 $mg \cdot kg^{-1}$) did not change total skill score or Stroop performance but tended to reduce misses and significantly lowered overall perceived fatigue during simulated competition.
Competition intensity and fatigue in elite fencing	Turner et al. (2017a)	Elite male foilists (2 competitions)	Knockout bouts elicited higher RPE, blood lactate and heart rate than poules (significant for RPE only); fencing behaves as a high-intensity anaerobic sport relying largely on alactic sources, with ample rest permitting high heart rates.
The effect of carbohydrate mouth rinsing on fencing performance and cognitive function following fatigue-inducing fencing	Rowlatt et al. (2017)	9 national-level epee fencers (crossover)	After fatiguing fencing, carbohydrate mouth rinsing improved lunge-test accuracy (81.2→87.6%) versus no change with placebo, with no effect on Stroop reaction time.
A loss of precision of movements in fencing due to increasing fatigue during physical exercise	Witkowski et al. (2019)	20 female Polish fencers (Olympic vs national)	Under an incremental fatiguing test, higher-proficiency fencers maintained movement precision whereas lower-proficiency fencers slowed significantly, despite similar blood-lactate responses across groups.
Physiological Profiling and Energy System Contributions During Simulated Epée Matches in Elite Fencers	Yang et al. (2022)	10 elite male fencers (simulated épée)	Simulated direct-elimination épée is high-intensity intermittent exercise with an oxidative contribution of ~80–90%; heart rate and oxidative share rose across bouts while glycolytic contribution fell, suggesting aerobic conditioning supports repeated actions.
Fatigue in elite fencing: Effects of a simulated competition	Varesco et al. (2023)	29 elite fencers (épée, sabre, foil)	Across a five-bout simulated competition, maximal knee-extensor torque (−1.6%/bout) and rate of torque development (−2.4%/bout) declined while perceived fatigue, effort and mental demand rose, indicating fencers increasingly allocate mental resources to offset fatigue.
The effects of facial cooling on physiological and perceptual responses during a	Morris & Glaister (2024)	6 competitive male fencers (crossover pilot)	Facial misting lowered tympanic temperature, heart rate and ratings of perceived exertion versus control, with perceptual benefits magnified as the

Title	Author(s), Year	Sample & level	Key findings
simulated Épée fencing competition: a pilot study			simulated competition progressed; performance effects were not tested.
Impacts of Season Phases and Training Variables on Mental Fatigue in Real-World Elite Fencing	Bian et al. (2025a)	31 elite fencers (15 F; 4-week longitudinal)	Mental fatigue rose after fencing activities and peaked on match days (+19.34 AU) alongside impaired reaction time (+76.43 ms); overall, tactical and physical training loads positively predicted mental fatigue.
Understanding of mental fatigue in elite fencing sports: perspectives from Chinese national level fencers	Bian et al. (2025b)	Tier 3–5 Chinese fencers (survey)	Mental fatigue was perceived as context-dependent (higher in direct-elimination than pool stages: 57.6 vs 49.2 AU), driven chiefly by decision-timing moments and offensive execution, prompting calls for deliberate mental-fatigue management.
Evolution of Mental Fatigue With Consecutive Match Progression in Elite Fencing	Bian et al. (2025c)	31 elite fencers (153 matches)	Mental fatigue accumulated across a competition day with a decelerating trend (theoretical increase +22.0%→+0.5%); only a negative hits-difference (receiving more hits) worsened accumulation, supporting early countermeasures.
Effects of 5-Week Brain Endurance Training on Fatigue and Performance in Elite Youth Epée Fencers	Varesco et al. (2025)	19 elite youth fencers (quasi-RCT)	Five weeks of brain endurance training prevented the reaction-time, attentional-lapse and perceived-fatigue impairments that a cognitive-fatiguing task produced in controls, without clearly improving fencing-test performance.
Analysis of the effect of fatigue in fencing using reaction time lights	Barañano-Alcaide et al. (2025)	48 fencers (simulated 15-point bout)	Most reaction times were significantly longer post-training than at rest, with decision-making tasks slowing by ~125–130 ms, showing that accumulated physical and mental fatigue degrades the speed and accuracy of fencers' responses.

Note. Sample nationality was not consistently reported in the source records; only Witkowski et al. (2019, Polish) and Bian et al. (2025b, Chinese) explicitly stated participant nationality.

Thematic and methodological classification

By mapping the studies to the review's research questions (Figure 3) we can see that fatiguing processes as the manifestations and development of physical mental exhaustion have been the primary topic of most researches (RQ1, n = 6) while the others have been distributed across the performance aspects of fatigue (RQ2, n = 4) and the countermeasures (RQ3, n = 4). Physical/physiological factors were the most common theme and mental fatigue was a prominent element too; three studies have been done on the interaction of physical and cognitive fatigue. Generally, reaction time and psychomotor speed were the dominant measures used, and the second most frequent measures involved the physiological/metabolic indicators and mental fatigue (subjective perception) and perceived physical fatigue (Figure 4).

Table 5. Classification of included studies by fatigue domain, research question, stimulus, and outcomes.

Author(s), Year	Fatigue domain	RQ	Fatiguing stimulus / intervention	Primary outcome measures
Obmiński et al. (1998)	Physical	RQ1	Repeated supramaximal exercise	Power output; hormones; lactate
Devienne et al. (2000)	Combined	RQ2	Local muscular fatigue (isometric)	Premotor/motor time; attention
Bottoms et al. (2013)	Physical	RQ3	Caffeine ingestion	Skill; perceived fatigue; RT
Turner et al. (2017a)	Physical	RQ1	Competition monitoring	HR; lactate; RPE; CMJ; hormones
Rowlatt et al. (2017)	Physical	RQ3	Carbohydrate mouth rinse	Lunge accuracy; RT
Witkowski et al. (2019)	Physical	RQ2	Incremental endurance test	Movement precision; lactate
Yang et al. (2022)	Physical	RQ1	Simulated épée matches	HR; VO_2; lactate; energy systems
Varesco et al. (2023)	Combined	RQ2	Simulated competition	Neuromuscular fatigability; perceived fatigue
Morris & Glaister (2024)	Physical	RQ3	Facial cooling	Temperature; HR; RPE
Bian et al. (2025a)	Mental	RQ1	Longitudinal season monitoring	Mental fatigue VAS; RT
Bian et al. (2025b)	Mental	RQ1	Cross-sectional survey	Perceived mental fatigue
Bian et al. (2025c)	Mental	RQ1	Intraday match monitoring	Mental fatigue; performance (hits)
Varesco et al. (2025)	Mental	RQ3	Brain endurance training	Sustained attention; RT; fatigue
Barañano-Alcaide et al. (2025)	Combined	RQ2	Simulated bout (RT lights)	Reaction time; HR; SO_2

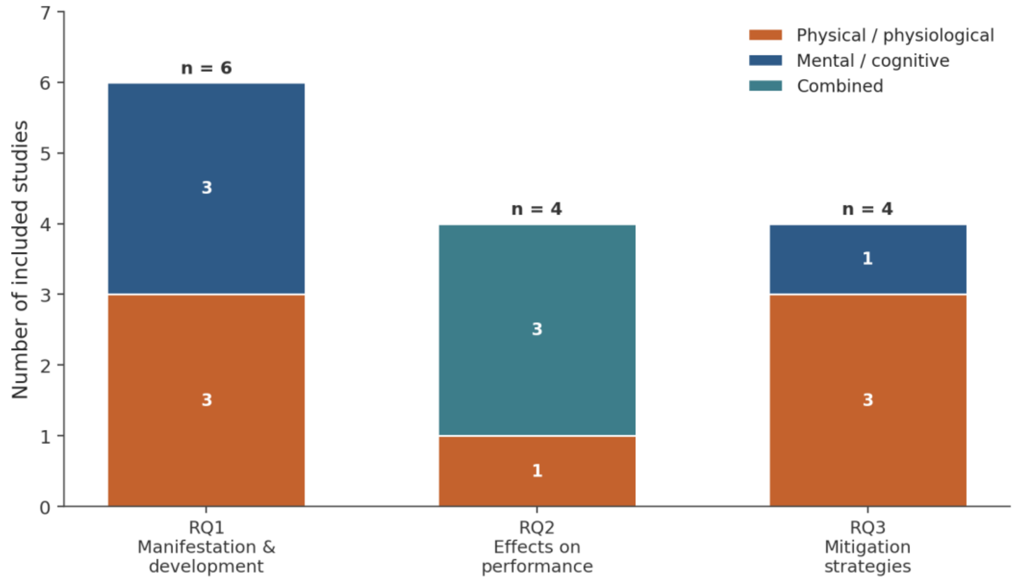

Figure 3. Distribution of the included studies across the three research questions and the physical, mental, and combined fatigue domains.

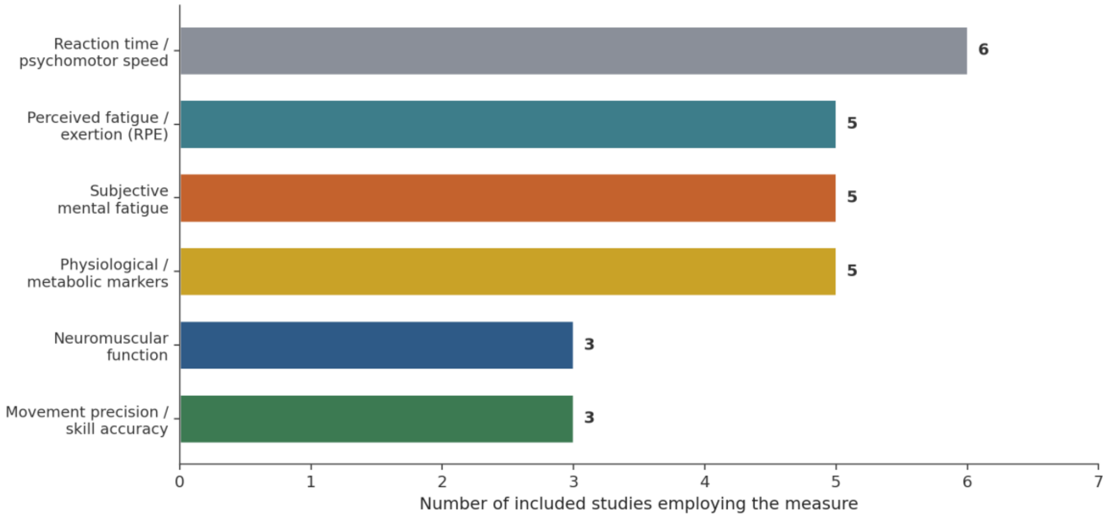

Figure 4. Frequency of fatigue-related measurement domains across the included studies. Individual studies frequently employed more than one measure.

Thematic synthesis

RQ1 - Manifestation and development of fatigue

A uniform image appears that through fencing, both the physical and the mental get tired, but each one in different ways. On the physical side, the description reveals that competitive and simulated fencing is high-intensity intermittent exercise: heart rates, blood lactate levels, and perceived exertion all increase from the pool stage to knockout stage. The oxidative system contributes about 80-90% of the energy throughout the repeated épée bouts, and the oxidative contribution becomes larger while the glycolytic contribution decreases as the bouts accumulate (Turner et al., 2017a; Yang et al., 2022). Nevertheless, it is not a complete physical fatigue scenario: rest periods during bouts as well as between the bouts are sufficient, the competitive workload may be rather light, and a repeated supramaximal protocol was proven to enhance the power output rather than fatiguing (Obmiński et al., 1998). When fatigue is intentionally elicited, neuromuscular fatigue remains, with the peak torque and the rate of torque development constantly decreasing throughout a simulated competition (Varesco et al., 2023).

On the other hand, mental fatigue grows gradually after training and competitions. Continuous mental fatigue can be detected through self-report questionnaires and other monitoring tools, with subjects reporting higher levels of mental fatigue after fencing, especially on match day. Tactical and physical workloads are the strongest predictors of mental fatigue (Bian et al., 2025a). When a full competition day is observed, the increase of mental fatigue is with a decelerating pattern, which means it worsens especially when a fencer receives more hits than they deliver (Bian et al., 2025c). Fencers, for their part, consider that the main causes of mental fatigue are the decision-timing moments and offensive action executions. In addition, they describe physical fatigue of mental work to be stronger in direct-elimination than that of pool stages (Bian et al., 2025b). Overall findings suggest that continuous cognitive demands of tactical processing contribute to fatigue more than metabolic strain.

RQ2 - Effects of fatigue on performance

The performance consequences of fatigue concentrate on the perceptual-motor outcomes that decide bouts. The most robust effect is a lengthening of reaction time: after a simulated bout, simple, elective, go/no-go, and especially decision-making reaction times increase markedly, with decision tasks slowing by roughly 125–130 ms (Barañano-Alcaide et al., 2025). Movement precision is also vulnerable, but its susceptibility depends on expertise; under an incremental fatiguing test, elite fencers preserved the accuracy and speed of their hits whereas less-proficient fencers deteriorated, despite comparable physiological responses (Witkowski et al., 2019). The mechanism appears to be partly compensatory: during a simulated competition, fencers reported rising mental demand and effort even as objective neuromuscular output fell, suggesting they increase the allocation of cognitive resources to protect performance against fatigue (Varesco et al., 2023).

The interaction between muscular fatigue and cognition is, however, not straightforward. An early experimental attempt to show that local muscular fatigue slows premotor and motor components of a choice-reaction fencing task found no reliable effect, a null result the authors attributed to large inter-individual variability and to an exercise stimulus that was not genuinely fatiguing (Devienne et al., 2000). This contrast, clear reaction-time costs when fatigue is accumulated realistically versus null effects when it is induced artificially and modestly, indicates that the ecological validity of the fatiguing protocol is decisive for detecting performance decrements.

RQ3 - Countermeasures and mitigation

Four studies tested countermeasures spanning nutritional, thermal, and cognitive approaches, each promising but constrained by small samples. Nutritionally, carbohydrate mouth rinsing improved lunge accuracy after fatiguing fencing without affecting reaction time (Rowlatt et al., 2017), and caffeine ingestion did not raise overall skill scores but tended to reduce misses and significantly lowered perceived fatigue (Bottoms et al., 2013). Thermally, facial misting during a simulated competition reduced tympanic temperature, heart rate, and perceived exertion, with benefits that grew as the competition progressed, although its effect on performance itself was not assessed (Morris & Glaister, 2024). The most direct attempt to counter the cognitive component was brain endurance training: five weeks of superimposed cognitive tasks protected sustained attention, reaction time, and perceived fatigue against a subsequent cognitive-fatiguing challenge in youth fencers, even though fencing-test performance did not clearly improve (Varesco et al., 2025). Collectively, the countermeasure evidence targets perceived and cognitive fatigue more successfully than objective performance, mirroring the RQ1 conclusion that the cognitive dimension is central.

Comparative and critical analysis

Across the 14 included studies, the evidence forms three broad patterns. Studies by Obmiński et al. (1998), Turner et al. (2017a), and Yang et al. (2022) primarily characterized physiological load and energy-system responses; Devienne et al. (2000), Witkowski et al. (2019), Varesco et al. (2023), and Barañano-Alcaide et al. (2025) connected fatigue induction or accumulation with perceptual-motor performance; Rowlatt et al. (2017), Bottoms et al. (2013), Morris and Glaister (2024), and Varesco et al. (2025) tested countermeasures; and Bian et al. (2025a, 2025b, 2025c) examined mental fatigue in real-world, survey, and repeated-match contexts. The studies converge on a pattern of increasing perceived/mental fatigue and selective performance decline, but they diverge in the magnitude and timing of neuromuscular effects. Importantly, the published evidence available under the predefined eligibility criteria comprised 14 studies, not 15 or more; a requirement to compare 15 eligible empirical studies cannot be met without changing the search or eligibility criteria. The revised synthesis therefore compares all 14 included studies explicitly and does not introduce an ineligible fifteenth study merely to satisfy a numeric threshold.

Taken together, the included studies suggest that fatigue in fencing cannot be understood as a purely metabolic phenomenon. Although fencing is physiologically demanding, its intermittent structure can limit sustained peripheral fatigue, while repeated anticipation, decision-making, and execution under time pressure may produce accumulating mental fatigue. The clearest and most repeatedly observed performance consequence is slower reaction time, while movement-precision losses appear more dependent on expertise and task demands.

The evidence therefore supports an integrated physical–cognitive interpretation, but the current literature does not justify the stronger claim that mental fatigue is universally the "primary" cause of performance decline.

Theoretically, the evidence is consistent with a psychobiological interpretation in which fatigue affects performance through interactions among effort perception, attentional control, and neuromuscular capacity rather than through peripheral decline alone. The observation that fencers increased perceived mental demand while objective neuromuscular output declined during simulated competition suggests compensatory allocation of cognitive resources (Varesco et al., 2023). Expertise may buffer precision loss under fatigue, as higher-proficiency fencers maintained movement precision despite increasing physiological strain (Witkowski et al., 2019). These findings provide a useful framework for future experimental work but should be treated as a mechanistic interpretation rather than direct causal evidence.

Three practical implications follow. First, monitoring should include both physical and mental load because competition-day mental fatigue may not be captured by physiological measures alone. Second, countermeasures should be evaluated against fencing-specific performance outcomes, not only perceived fatigue or physiological responses. Third, aerobic and neuromuscular conditioning remain relevant foundations for repeated high-intensity actions, but nutritional, thermal, and cognitive strategies should be presented as preliminary or task-specific rather than established performance enhancers.

Situated against the wider literature, this review complements recent syntheses of acute performance in combat sports and of fencing injury epidemiology, which likewise stress cumulative competitive load and its risks (Kons et al., 2020; Wong et al., 2025; Leung et al., 2026). It also connects with emerging tools such as gaze-behaviour analysis, digit-force profiling, and immersive virtual-reality warm-ups that may eventually be harnessed to detect or offset fatigue in real time (Vincze et al., 2026; Akbaş et al., 2026; Bian et al., 2026). Nonetheless, contradictions remain: null experimental effects of induced muscular fatigue on cognition (Devienne et al., 2000) sit alongside clear field-based decrements, and countermeasures improve perceived or cognitive outcomes more reliably than objective performance, underlining how sensitive conclusions are to protocol and outcome choice.

Limitations

This review has several limitations that constrain inference. First, the evidence base is small and heterogeneous, with predominantly elite or national-level samples and limited representation of women, youth outside elite pathways, wheelchair fencers, and sabre-specific fatigue research. Second, mental fatigue was often assessed with subjective scales, which are useful for ecological monitoring but may be affected by reporting and measurement reactivity; future studies should triangulate self-report with objective vigilance, reaction-time, and task-performance measures. Third, the reviewed studies used different fatigue-induction procedures and outcomes, limiting direct effect-size comparison and supporting the decision not to conduct a meta-analysis. Fourth, the search covered only Scopus, PubMed, and ScienceDirect and excluded grey literature, manual searching, and citation chasing, creating a risk of publication and retrieval bias. Fifth, inter-rater agreement was not prospectively recorded in the retained workflow, preventing retrospective calculation of Cohen's kappa. These limitations mean that the conclusion should be interpreted as a structured synthesis of a small and heterogeneous evidence base rather than a definitive causal estimate.

Research gaps and future directions

Future studies should prioritize ecologically valid fatigue protocols that measure neuromuscular and cognitive fatigue concurrently with fencing-specific performance. Studies should also pre-specify primary outcomes, include sex- and weapon-stratified analyses where feasible, and combine subjective fatigue measures with objective psychomotor metrics. For planning, the manuscript now gives a transparent statistical example rather than presenting an unsupported fixed sample size: for a two-group comparison targeting a moderate standardized effect ($d = 0.50$), two-sided alpha = 0.05, and 80% power, a conventional independent-samples calculation requires approximately 64 participants per group (128 total) before attrition. With 10% attrition, the recruitment target would be about 142 participants. This is an illustrative planning scenario, not an effect estimate derived from the present review; crossover and repeated-measures designs require their own power calculations. Future intervention trials should therefore conduct an a priori power analysis using an outcome-specific effect estimate and account for expected dropout and design structure.

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Conclusions

This systematic review included 14 primary empirical studies published between 1998 and 2025 and identified evidence of both physical and mental fatigue in competitive fencing. Searches of Scopus, PubMed, and ScienceDirect yielded 295 records; after 15 duplicates were removed, 280 records were screened, 44 reports were assessed in full text, and 14 studies met the predefined eligibility criteria. MMAT scores ranged from 3.5 to 5.0, with 11 studies rated high and three medium. Across the evidence, neuromuscular fatigability was generally modest and appeared partly buffered by expertise, whereas perceived and mental fatigue accumulated across training or competition. Reaction time showed the most consistent performance decrement, while movement-precision effects were more evident among less-proficient fencers. Nutritional, thermal, and cognitive countermeasures showed preliminary benefits for selected perceptual or physiological outcomes, but robust improvements in objective fencing performance remain unconfirmed. Because the evidence base is small, heterogeneous, English-language only, and derived from three databases without grey-literature or citation-chasing procedures, the conclusions should be interpreted cautiously. Future trials should measure physical and mental fatigue concurrently, use fencing-specific performance outcomes, and perform an a priori power analysis; as an illustrative planning benchmark, a two-group trial targeting d = 0.50 at 80% power would require approximately 128 participants before attrition, but the final sample must be determined from the study's design and primary outcome.

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