Vol. 7, No. 1, 2026, pp. 1509-1523
DOI: https://doi.org/10.29210/993730

Contents lists available at Elora Center

Lentera Negeri

Journal homepage: https://lentera.eloracenter.org/lentera

Anticipation and decision-making in fencing: a systematic review of neuromuscular and cognitive correlates

Ade Zalindro[*)], M. Arie Desman, Rudyanto Rudyanto
Universitas Negeri Padang, Indonesia

Article Info

Article history:
Received Sept 03rd, 2026
Revised Sept 06th, 2026
Accepted Sept 07th, 2026

Keyword:
Fencing,
Anticipation,
Decision-making,
Electromyography,
Perceptual-cognitive expertise

ABSTRACT

This review evaluated how neuromuscular, perceptual-cognitive, neural, and training-related markers are associated with anticipation and decision-making in fencing, and identified consistency and methodological limitations. Scopus, PubMed, and ScienceDirect were searched using predefined PICOS-based terms. Of 114 records, 15 duplicates were removed, 99 records screened, 34 full texts assessed, and 22 reports included: 21 empirical studies and one narrative review for contextual synthesis. Study quality was appraised using the MMAT 2018. Participant totals were not pooled because a verified cross-study count was unavailable and overlapping cohorts could cause double counting. Meta-analysis was not defensible because outcomes, tasks, instruments, comparison groups, and reporting formats were heterogeneous; findings were synthesised narratively according to SWiM principles. Inter-rater kappa was not calculated and could not be reconstructed retrospectively. Expertise was associated with earlier muscle activation, more economical EMG coordination, faster or stable responses, stronger cortical preparation, and efficient visual search. Evidence for trainability remained limited.

Corresponding Author:
Ade Zalindro,
zalindro@fik.unp.ac.id

Introduction

Combat sports require athletes to integrate perception, anticipation, action selection, and motor execution under severe time pressure. Fencing is a particularly demanding open-skill combat sport because attacks, feints, parries, and counterattacks unfold within brief windows in which the athlete must interpret task-relevant cues and translate them into accurate action (De Quel & Bennett, 2019). This makes fencing a useful model for studying perception-action expertise and decision-making.

In this review, anticipation is operationalised as preparation for an action before the opponent's movement is fully observable. We treat this construct at several measurable levels: early postural or limb-muscle activation, anticipatory postural adjustments, response and movement timing, response inhibition or amendment, gaze allocation, and neural markers of preparatory control. Perceptual-cognitive expertise refers to the efficient selection and interpretation of task-relevant information that supports an appropriate action. These definitions allow apparently different behavioural, neuromuscular, ocular, and neural measures to be considered within one framework without assuming that they represent the same mechanism.

Previous fencing research has examined these components separately. Electromyography (EMG), kinematics, and ground-reaction forces have been used to characterise the lunge and flèche, while reaction-time paradigms have compared experts with less-skilled fencers under different stimulus and response conditions (Borysiuk & Bailey, 2007; Williams & Walmsley, 2000a). EEG and event-related-potential studies have addressed cortical preparation and executive control (Del Percio et al., 2007, 2008; Taddei et al., 2012; Bianco et al., 2017). Eye-tracking has also begun to examine visual-search behaviour in fencing referees (Babadi et al., 2021), but direct gaze measurement during live fencing remains uncommon.

The central methodological gap is not the absence of individual measures, but the lack of integration across measurement levels and the limited ability to distinguish association from causation. Most studies use single-modality or laboratory tasks, small samples, and cross-sectional expertise contrasts. Consequently, it remains unclear whether peripheral preparatory activity, gaze behaviour, and cortical preparation are coordinated expressions of the same perception-action process or simply parallel correlates of expertise. Simultaneous recording of EMG, kinematics/force, gaze, and neural activity during representative fencing actions would be better suited to testing that relationship. The present systematic review therefore maps the available evidence across these modalities and explicitly evaluates its methodological strength and boundary conditions.

A second gap concerns transfer and trainability. Although studies report expertise-related differences, relatively few examine longitudinal change or interventions, and wheelchair fencing introduces different neuromuscular constraints that limit direct extrapolation from able-bodied athletes (Borysiuk et al., 2020; Borysiuk et al., 2022b; Borysiuk et al., 2023). Evidence for eye-tracking, virtual reality, and AI-supported analysis is also much thinner than the literature on EMG and reaction time. A systematic synthesis is therefore needed to distinguish established correlates from promising but preliminary technologies.

The practical rationale is equally important. Coaches increasingly have access to sensor-based feedback, reaction-light systems, gaze tracking, and immersive technologies, but these tools should be interpreted in proportion to the underlying evidence. A transparent systematic review can identify which markers are repeatedly associated with expertise, which findings are context-dependent, and which interventions have actually been tested rather than merely proposed.

Accordingly, the review is structured around three research questions. RQ1 examines neuromuscular and physiological signatures of anticipation and response execution. RQ2 examines perceptual-cognitive processes and their neural correlates, including reaction, inhibition, gaze, and EEG/ERP measures. RQ3 examines training and technology approaches that have been evaluated for improving anticipation and decision-making. The synthesis is deliberately association-focused and does not infer causality from cross-sectional expertise contrasts.

RQ1 concerns neuromuscular and physiological indicators, including EMG timing and coordination, postural adjustments, ground-reaction forces, kinematics, and response timing that differ across expertise levels.

RQ2 concerns perceptual-cognitive processes and neural correlates, including visual search, decision accuracy, response inhibition, reaction-time control, EEG/ERP markers, and anticipatory cortical preparation.

RQ3 concerns evaluated training and technology approaches, including perceptual training, reaction-time programmes, fatigue-related performance changes, and emerging virtual-reality or AI applications where empirical fencing evidence exists.

RQ1: What neuromuscular and physiological signatures distinguish anticipation and response execution across fencers of differing expertise?

RQ2: How do perceptual-cognitive processes and their neural correlates underpin anticipation and decision-making in fencing?

RQ3: Which training and technological approaches have been evaluated for enhancing anticipation and decision-making in fencing, and what evidence supports them?

Method

Research Design and Framework

This study is a systematic literature review (SLR) of empirical fencing research, reported according to PRISMA 2020 (Page et al., 2021). The review protocol was defined prospectively at the level of the research questions, PICOS concepts, eligibility criteria, and synthesis plan. Because this was a review rather than a primary experiment, no participant-level power analysis or a priori sample-size calculation was applicable; the review sample was determined by the prespecified database search and eligibility process. The synthesis was structured around the three research questions and used a narrative approach because the included studies differed substantially in participants, fencing tasks, outcomes, instruments, and comparison structures.

Search Strategy
Prior to constructing the search string, the review questions were decomposed using the PICOS framework to ensure systematic identification of the key search concepts, as summarised in Table 1.

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

Element	Specification for this review
Population (P)	Competitive fencers (foil, épée, sabre; able-bodied and wheelchair; novice to elite)
Intervention / Interest (I)	Anticipation, perceptual-cognitive demand, technical execution (lunge, flèche), and training or technological interventions
Comparison (C)	Expertise contrasts (elite vs novice), stimulus or load conditions, or pre- vs post-training (where applicable)
Outcome (O)	EMG / neuromuscular indices, ground reaction forces and kinematics, reaction / movement / decision time, gaze and visual-search metrics, and EEG / ERP correlates
Study design (S)	Empirical quantitative studies (descriptive, non-randomised, experimental) and relevant narrative reviews

Each PICOS element was translated into a cluster of keywords and synonyms, which were combined with Boolean operators. The exact search string is presented below.

("fenc*" OR "épée" OR "epee" OR "foil" OR "sabre") AND ("anticipat*" OR "decision*" OR "reaction time" OR "perceptual-cognitive" OR "visual search") AND ("EMG" OR "electromyograph*" OR "EEG" OR "eye track*" OR "kinematic*" OR "ground reaction force")

The search string was applied to Scopus TITLE-ABS-KEY fields and to the closest title/abstract fields available in PubMed and ScienceDirect. English-language peer-reviewed articles and reviews were eligible at the search stage. The search string was pilot-tested and refined for sensitivity and specificity; the final string reported here is the string used for the review. No additional boxing-related concept cluster was part of the final search string, so the previous wording implying that such a cluster was retained has been removed for consistency.

Database and Information Sources
Scopus, PubMed, and ScienceDirect were searched as complementary databases covering sport science, biomedical, and interdisciplinary literature. The records were exported, merged, and deduplicated before title/abstract screening. The review did not claim exhaustive coverage of all databases; this limitation is reflected in the Discussion.

Eligibility Criteria

Table 2. Inclusion and exclusion criteria.

Criterion	Inclusion	Exclusion
Population	Competitive fencers (any weapon; able-bodied or wheelchair)	Non-fencing samples or general-athlete samples without fencing data
Focus	Anticipation, decision-making, reaction/response, or their neuromuscular/neural correlates	Studies without a target perceptual-cognitive or neuromuscular outcome
Document type	Peer-reviewed article or review	Conference paper, erratum, book chapter, editorial, protocol
Language	English	Non-English
Data	Primary empirical data or directly relevant synthesis	Purely conceptual or opinion pieces without data
Accessibility	Full text retrievable	Abstract only / not retrievable

Study Selection Process
Study selection followed the PRISMA sequence: 114 records were identified (Scopus n = 93, PubMed n = 15, ScienceDirect n = 6); 15 duplicates were removed, leaving 99 records for title/abstract screening; 65 were excluded at screening; 34 full-text reports were sought and retrieved; and 12 were excluded at full text, leaving 22 reports for synthesis. Full-text exclusions were: non-fencing/non-target sample (n = 5), review or conceptual paper without primary fencing data (n = 3), overlapping wheelchair-fencing data (n = 2), outcome

outside the target constructs (n = 1), and study protocol without outcome data (n = 1). Selection decisions were checked against the prespecified criteria. Inter-rater Cohen's kappa was not calculated in the original workflow, so no numerical agreement coefficient can be reported retrospectively without inventing data; this is now identified explicitly as a reporting limitation.

Quality Assessment

Quality Assessment: The included reports were appraised with the Mixed Methods Appraisal Tool (MMAT), version 2018 (Hong et al., 2018), selected because it accommodates descriptive quantitative, non-randomised quantitative, and experimental designs within one appraisal framework. The five design-specific criteria were recorded as Yes, can't tell/Partial, or No. Criterion-level judgments were retained as the primary quality evidence; the descriptive totals shown in Table 3 are not treated as a formal global MMAT score, and no study was excluded solely on the basis of appraisal. The narrative review included in the 22-report corpus was retained only for contextual synthesis and was not used to support claims about effects in fencing participants.

Table 3. MMAT quality-appraisal summary of the 22 included studies (Q1–Q5 = the five design-specific MMAT criteria).

Study	Design	Q1	Q2	Q3	Q4	Q5	Total	Rating
Williams & Walmsley (2000a)	Quant. non-randomised	1	1	1	0.5	1	4.5/5 (90%)	High
Williams & Walmsley (2000b)	Quant. non-randomised	1	1	0.5	0.5	1	4/5 (80%)	High
Borysiuk & Bailey (2007)	Quant. non-randomised	1	1	1	0.5	1	4.5/5 (90%)	High
Borysiuk & Waśkiewicz (2008)	Quant. descriptive	1	0.5	1	0.5	1	4/5 (80%)	High
Borysiuk (2008)	Quant. non-randomised	1	1	1	0.5	0.5	4/5 (80%)	High
Taddei et al. (2012)	Quant. non-randomised	1	1	1	1	1	5/5 (100%)	High
Zhang et al. (2015)	Quant. non-randomised	1	1	1	0.5	1	4.5/5 (90%)	High
Balkó et al. (2016)	Quant. non-randomised	1	1	1	0.5	1	4.5/5 (90%)	High
Gutiérrez-Davila et al. (2016)	Quant. experimental	1	1	1	1	1	5/5 (100%)	High
Bianco et al. (2017)	Quant. non-randomised	1	1	1	1	1	5/5 (100%)	High
Balkó et al. (2018)	Quant. non-randomised	1	1	1	0.5	1	4.5/5 (90%)	High
Borysiuk et al. (2018)	Quant. non-randomised	1	1	0.5	0.5	1	4/5 (80%)	High
Borysiuk et al. (2019)	Quant. descriptive	1	1	1	0.5	1	4.5/5 (90%)	High
Borysiuk et al. (2020)	Quant. descriptive	1	0.5	1	0.5	1	4/5 (80%)	High
Babadi et al. (2021)	Quant. non-randomised	1	1	1	1	1	5/5 (100%)	High
Akbaş et al. (2021)	Quant. non-randomised	1	1	1	1	1	5/5 (100%)	High
Borysiuk et al. (2022a)	Quant. descriptive	1	1	0.5	0.5	1	4/5 (80%)	High
Kim et al. (2023)	Quant. non-randomised	1	1	1	0.5	1	4.5/5 (90%)	High
Borysiuk et al. (2024)	Quant. descriptive	1	1	1	1	1	5/5 (100%)	High
Barañano-Alcaide et al. (2025)	Quant. experimental	1	1	1	1	1	5/5 (100%)	High
Teteris et al. (2025)	Quant. non-rand. (pilot)	1	1	0.5	0.5	1	4/5 (80%)	High
Borysiuk (2025)	Narrative review	1	0.5	0.5	1	1	4/5 (80%)	High

Note. MMAT criterion-level judgments are the primary appraisal evidence; the arithmetic totals are descriptive summaries only and were not used as a stand-alone exclusion threshold.

Data Extraction Procedure

Data extraction recorded authors, year, country, design, sample characteristics when reported, expertise level, weapon, measurement modality (EMG, kinematics/GRF, reaction/decision time, eye-tracking, or EEG/ERP), intervention or experimental manipulation, outcome indicators, and key findings. Participant numbers were retained at study level rather than summed across the corpus because overlapping cohorts could otherwise inflate an aggregate N.

Bibliometric and Descriptive Analysis

We have presented some descriptive bibliometric data in tabular and diagrammatic form that reflect temporal distribution, geographic origin, distribution of measurement approaches, and main thematic clusters. This is to help portray the main features of the evidence base and provide an analytical framework for the qualitative synthesis. Please read Figure 2-4 for more on that.

Data Analysis and Synthesis

Because the included studies were heterogeneous in design, tasks, constructs, measurement units, and reporting formats, quantitative pooling was not considered methodologically defensible. The synthesis therefore followed a structured narrative approach informed by the SWiM reporting principles (Campbell et al., 2020). Evidence was grouped by RQ and modality. When findings conflicted, priority was given to direct fencing tasks over indirect transfer tasks, empirical primary studies over narrative commentary, and findings replicated across independent samples; discordant findings were retained and discussed rather than vote-counted. Effect sizes or forest plots were not generated where the source reports did not provide sufficiently compatible statistics for valid pooling.

Reporting and Documentation

The review followed PRISMA 2020 for reporting (Page et al., 2021). Figure 1 presents the exact identification, screening, eligibility, and inclusion counts, while Tables 3-5 present appraisal and study-level synthesis. The reporting distinguishes 22 included reports from the 21 empirical studies that provide participant-based findings.

PRISMA 2020 Flow Diagram

The PRISMA flow was: records identified = 114 (Scopus 93; PubMed 15; ScienceDirect 6); duplicates removed = 15; records screened = 99; records excluded at title/abstract = 65; full-text reports sought = 34; reports not retrieved = 0; reports assessed for eligibility = 34; full-text exclusions = 12; and reports included = 22. These counts are identical across the Methods, Results, and Figure 1. Because inter-rater decisions were not stored as a two-rater dataset, a retrospective kappa coefficient cannot be reconstructed. Likewise, an aggregate participant N is not presented because the extracted corpus did not preserve a verified non-overlapping participant denominator.

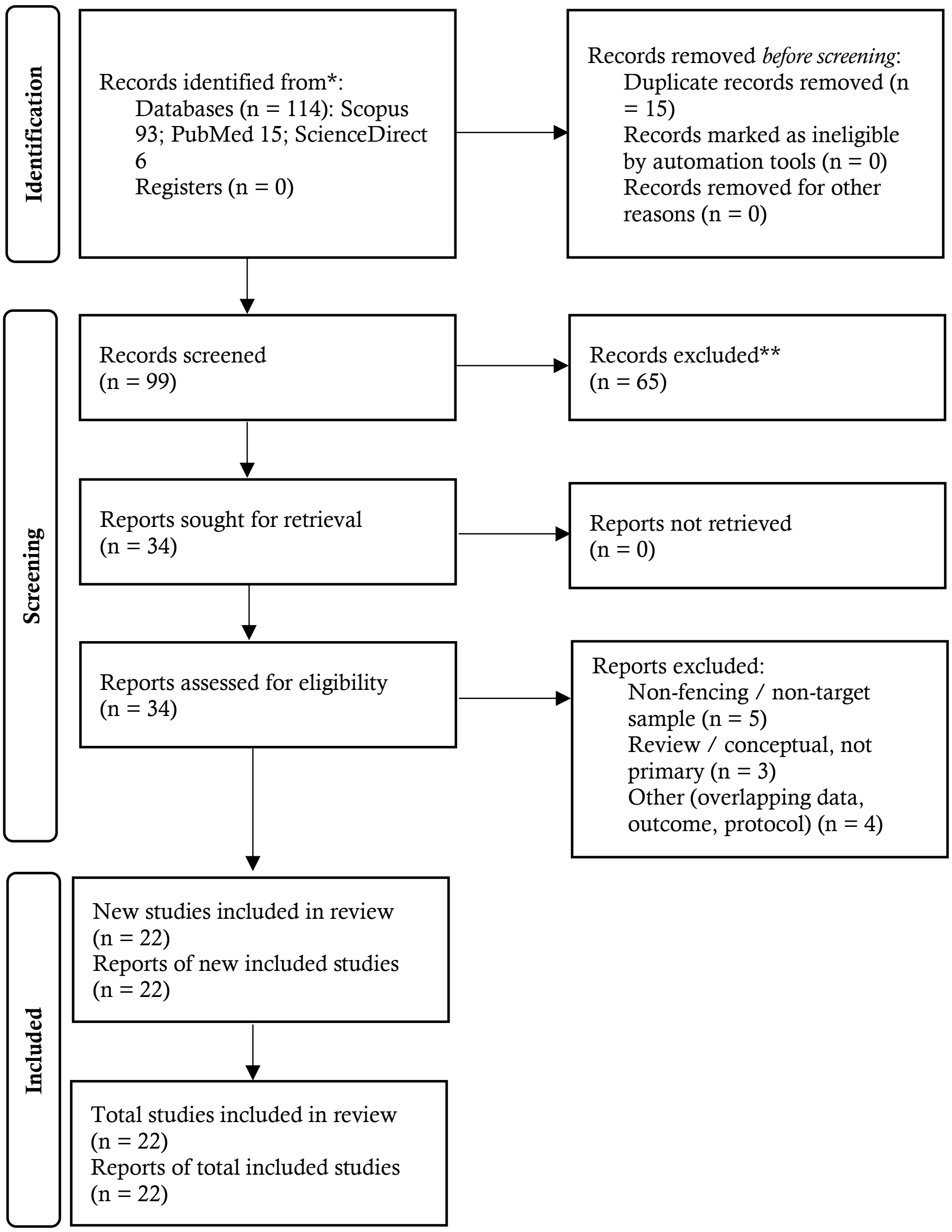

Figure 1. PRISMA 2020 flow diagram of the study selection process (adapted from Page et al., 2021).

Results and Discussions

Study Selection Results

The systematic search identified 114 records from Scopus (93), PubMed (15), and ScienceDirect (6). After removal of 15 duplicates, 99 unique records were screened by title and abstract, of which 65 were excluded. Thirty-four full-text reports were assessed; 12 were excluded for prespecified reasons, leaving 22 included reports. The corpus therefore comprises 21 empirical studies and one narrative review used only to contextualise eye-tracking evidence. The PRISMA counts are shown consistently in Figure 1.

Descriptive Characteristics

The 22 reports span 2000-2025 and 10 countries. Poland contributes nine reports, many from the same research group, while other contributions come from Italy, Spain, the Czech Republic, New Zealand, China, Iran, South Korea, and Latvia. Most studies are cross-sectional or non-randomised expertise comparisons with relatively small samples. Only two reports were experimental comparisons and one was a 12-week pilot intervention. Because the review database did not preserve a verified non-overlapping participant denominator, participant counts are reported at study level where available rather than summed across studies. The study-level characteristics are provided in Table 4, and the modality/outcome classification is summarised in Table 5. The descriptive MMAT totals ranged from 80% to 100%: seven reports were 100%, seven were 90%, and eight were 80%. These arithmetic summaries are reported for transparency, while the design-specific criterion judgments remain the substantive appraisal evidence.

Table 4. Summary of the 22 included studies (full titles; concise complete key findings).

Title	Author(s) (Year)	Country	Method	Key findings
Response timing and muscular coordination fencing: A comparison of elite and novice fencers	Williams & Walmsley (2000a)	New Zealand	Expertise contrast; RT/MT + EMG	Elite fencers showed faster, more consistent reaction and movement times than novices across target-choice and lunge-distance conditions, with more economical muscular coordination.
Response amendment in fencing: Differences between elite and novice subjects	Williams & Walmsley (2000b)	New Zealand	Dual-response paradigm; RT/MT + EMG	Under a dual-response amendment paradigm, elite fencers corrected ongoing responses faster and more accurately than novices, indicating superior online movement control.
Influence of stimuli type on electromyography (EMG) signal, reaction and movement time in novice and advanced fencers	Borysiuk & Bailey (2007)	Poland/UK	Expertise contrast; EMG + RT/MT	Stimulus modality shaped EMG, reaction and movement time; advanced fencers responded faster than novices, and tactile stimuli elicited the quickest responses.
Information Processes, Stimulation and Perceptual Training in Fencing	Borysiuk & Waśkiewicz (2008)	Poland	Information-processing analysis	Framed fencing skill acquisition through information-processing theory, arguing that multisensory perceptual training structures open-skill motor habits.
Psychomotor reactions in fencing dependence of stimuli type	Borysiuk (2008)	Poland	Stimulus-type comparison; RT/MT + EMG	Reaction and movement time and EMG differed by stimulus type, with tactile stimulation fastest and advanced fencers outperforming beginners.
Neural correlates of attentional and executive processing in middle-age fencers	Taddei et al. (2012)	Italy	Cross-sectional; EEG/ERP	Middle-aged fencers retained attentional and executive ERP components comparable to young adults, suggesting open-skill practice buffers age-related cognitive decline.
Enhanced response inhibition in experienced fencers	Zhang et al. (2015)	China	Group comparison; response inhibition	Experienced fencers showed enhanced response inhibition versus non-athletes, indicating training-related gains in suppressing prepotent responses.
The influence of different performance level of fencers on muscular coordination and reaction time during the fencing lunge	Balkó et al. (2016)	Czech Rep.	Level comparison; EMG + RT	Higher-level fencers exhibited shorter reaction times and distinct muscular coordination during the lunge relative to lower-level fencers.
Time required to initiate a defensive reaction to direct and feint attacks in fencing	Gutiérrez-Davila et al. (2016)	Spain	Experimental; kinematics + decision timing	Fencers were slower to initiate defence against feints than direct attacks; feints delayed detection of the just-noticeable difference, quantifying the cost of deception.

Title	Author(s) (Year)	Country	Method	Key findings
Different proactive and reactive action control in fencers' and boxers' brain	Bianco et al. (2017)	Italy	Group comparison; EEG/ERP	Fencers and boxers showed distinct proactive versus reactive cortical control; fencing was associated with stronger anticipatory (proactive) preparation.
Relationship between the armed arm's motor response and muscle activation time during the lunge in fencers of varied ability	Balkó et al. (2018)	Czech Rep.	Ability comparison; surface EMG	Armed-arm muscle activation timing during the lunge varied with ability; more skilled fencers showed more efficient agonist–antagonist sequencing.
Fencing Flèche performed by elite and novice épéeists depending on type of perception	Borysiuk et al. (2018)	Poland	Expertise contrast; EMG + kinematics	Flèche movement patterns differed between elite and novice épéeists and depended on whether visual or tactile perception guided the action.
Flèche versus lunge as the optimal footwork technique in fencing	Borysiuk et al. (2019)	Poland	Competition analysis; effectiveness	In competition analysis, the flèche produced greater attacking effectiveness than the lunge, informing evidence-based technique selection.
Neuromuscular, Perceptual, and Temporal Determinants of Movement Patterns in Wheelchair Fencing: Preliminary Study	Borysiuk et al. (2020)	Poland	Preliminary; EMG + kinematics	Wheelchair-fencing lunge patterns were shaped by neuromuscular, perceptual and temporal determinants and differed across disability categories A and B.
Comparison of Visual Search Behavior and Decision-making Accuracy in Expert and Novice Fencing Referees	Babadi et al. (2021)	Iran	Expertise contrast; eye-tracking	Expert fencing referees used fewer, longer fixations and achieved higher decision-making accuracy than novices, evidencing gaze-based perceptual-cognitive expertise.
Two Aspects of Feedforward Control During a Fencing Lunge: Early and Anticipatory Postural Adjustments	Akbaş et al. (2021)	Poland	Expertise contrast; posturography	Expertise modulated early and anticipatory postural adjustments preceding the lunge, reflecting refined feedforward control in skilled fencers.
EMG structure, ground reaction forces as anticipatory indicators of the fencing lunge effectiveness	Borysiuk et al. (2022a)	Poland	Cross-sectional; EMG + GRF	EMG onset and ground reaction forces during the preparatory phase served as anticipatory indicators of straight-lunge effectiveness in épée.
Low Activation of Knee Extensors and High Activation of Knee Flexors in Female Fencing Athletes Is Related to the Response Time during the Marche-Fente	Kim et al. (2023)	South Korea	Cross-sectional; EMG + RT	In female fencers, lower knee-extensor and higher knee-flexor activation related to response time during the marche-fente, revealing muscle-specific timing determinants.
The phenomenon of anticipation in fencing. An applicability approach	Borysiuk et al. (2024)	Poland	Cross-sectional; EMG + GRF + mocap	Anticipatory EMG activation preceded vertical ground-reaction force by ~15–30 ms during the lunge; the preparatory period was decisive for lunge effectiveness.
Analysis of the effect of fatigue in fencing using reaction time lights	Barañano-Alcaide et al. (2025)	Spain	Fatigue experiment; RT + HR/SpO2	Fencing-induced physical and mental fatigue lengthened reaction time to light stimuli, linking autonomic load (heart rate, oxygen

Title	Author(s) (Year)	Country	Method	Key findings
				saturation) to perceptual-motor slowing.
Application of the Vienna Test System to Measure Training-Induced Changes in Choice Reaction Time in U20 Fencers: A 12-Week Training Program Pilot Study	Teteris et al. (2025)	Latvia	12-week pilot; choice RT (VTS)	A 12-week reaction-training programme improved choice reaction time in U20 fencers, supporting the trainability of cognitive-motor speed.
Eye-Tracking Analysis of Perceptual-Cognitive Processes in Combat Sports: A Narrative Review	Borysiuk (2025)	Poland	Narrative review; eye-tracking	Synthesised eye-tracking findings in combat sports, concluding that expert gaze is more efficient and anticipatory, and proposing practical perceptual-training guidelines.

Table 5. Summary of the 22 included studies (full titles; concise complete key findings).

Author(s) (Year)	Country	Theme (RQ)	Measurement modality	Primary outcome
Williams & Walmsley (2000a)	New Zealand	RQ1	RT/MT; EMG	RT/MT, accuracy
Williams & Walmsley (2000b)	New Zealand	RQ2	RT/MT; EMG	Amendment time, accuracy
Borysiuk & Bailey (2007)	Poland/UK	RQ2	EMG; RT/MT	RT/MT, EMG onset
Borysiuk & Waśkiewicz (2008)	Poland	RQ3	Perceptual training	Skill-acquisition model
Borysiuk (2008)	Poland	RQ2	RT/MT; EMG	RT/MT, EMG
Taddei et al. (2012)	Italy	RQ2	EEG/ERP	ERP amplitude/latency
Zhang et al. (2015)	China	RQ2	Behavioural inhibition	Inhibition performance
Balkó et al. (2016)	Czech Rep.	RQ1	EMG; RT	RT, muscle timing
Gutiérrez-Davila et al. (2016)	Spain	RQ1	Kinematics; decision	Defensive-reaction time
Bianco et al. (2017)	Italy	RQ2	EEG/ERP	Cortical preparation
Balkó et al. (2018)	Czech Rep.	RQ1	EMG	Muscle activation time
Borysiuk et al. (2018)	Poland	RQ1	EMG; kinematics	Movement pattern
Borysiuk et al. (2019)	Poland	RQ1	Kinematics	Attack effectiveness
Borysiuk et al. (2020)	Poland	RQ1	EMG; kinematics	Movement pattern
Babadi et al. (2021)	Iran	RQ2	Eye-tracking	Fixations, decision accuracy
Akbaş et al. (2021)	Poland	RQ1	Posturography	Postural-adjustment onset
Borysiuk et al. (2022a)	Poland	RQ1	EMG; GRF	EMG/GRF anticipation
Kim et al. (2023)	South Korea	RQ1	EMG; RT	Muscle activation, RT
Borysiuk et al. (2024)	Poland	RQ1	EMG; GRF; mocap	Anticipatory EMG–GRF lag
Barañano-Alcaide et al. (2025)	Spain	RQ3	RT; HR/SpO2	RT under fatigue
Teteris et al. (2025)	Latvia	RQ3	Choice RT (VTS)	Choice RT change
Borysiuk (2025)	Poland	RQ2	Eye-tracking	Gaze-efficiency synthesis

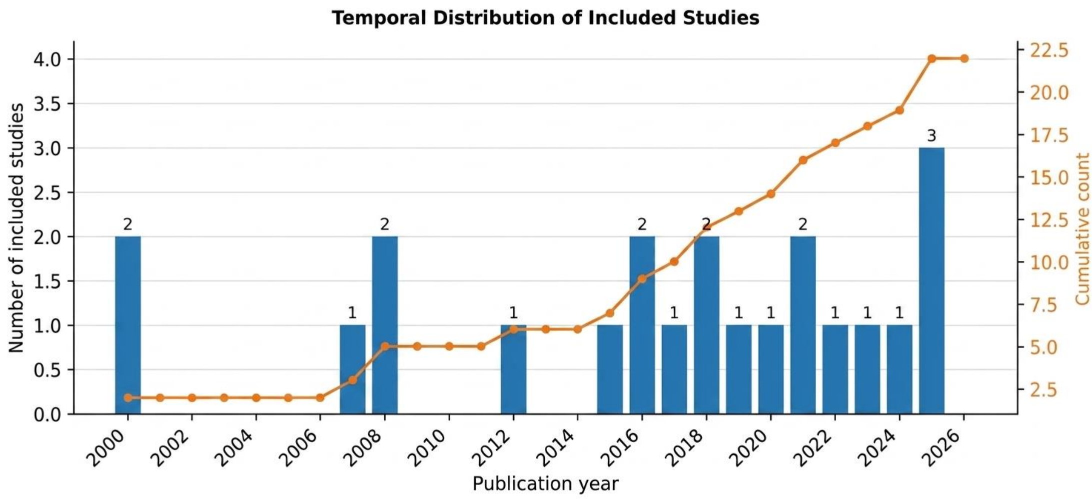

Figure 2. Annual and cumulative distribution of the 22 included fencing studies (2000–2026).

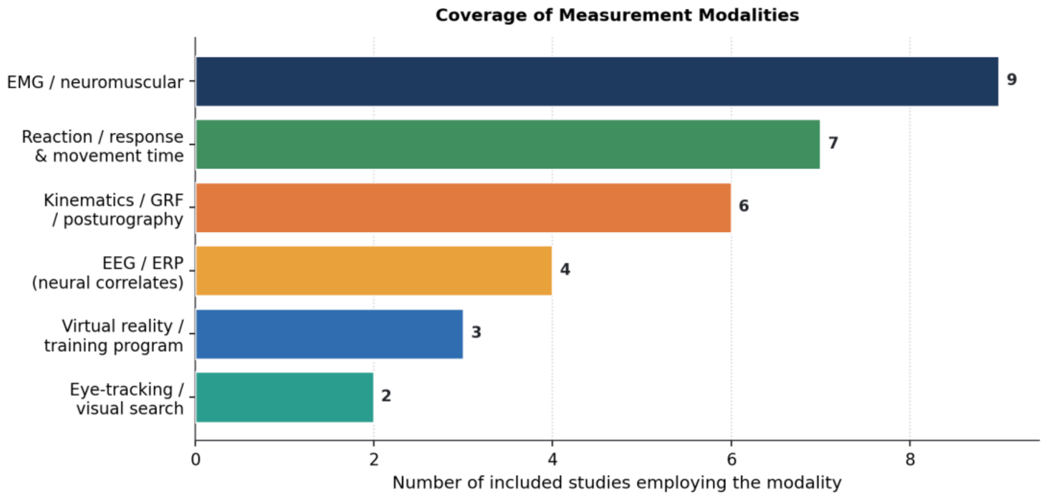

Figure 3. Coverage of measurement modalities across included studies; studies may employ more than one modality.

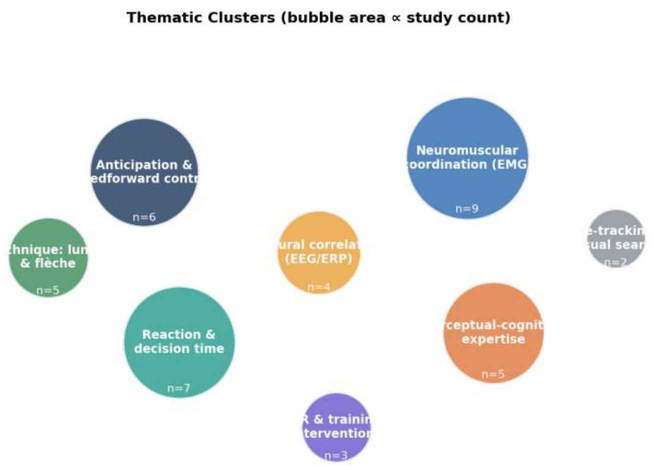

Figure 4. Thematic clusters derived from the 22 included studies; bubble area is proportional to the number of studies.

Thematic Synthesis

Findings for RQ1 - Neuromuscular and physiological determinants

Eleven empirical reports addressed neuromuscular or biomechanical determinants of anticipation and response execution. Across expertise-comparison studies, the clearest pattern was not simply faster movement, but earlier and better-organised preparation. Williams and Walmsley (2000a, 2000b), Borysiuk and Bailey (2007), Borysiuk (2008), Balkó et al. (2016, 2018), Borysiuk et al. (2018), Kim et al. (2023), and Borysiuk et al. (2022a, 2024) collectively indicate that skilled fencers show earlier muscle activation, more economical agonist-antagonist sequencing, faster responses, or better response amendment. Borysiuk et al. (2024) reported an anticipatory EMG lead of approximately 15-30 ms relative to vertical ground-reaction force, linking the preparatory phase to successful lunge execution. Importantly, these studies demonstrate associations between expertise and preparation, not a causal effect of expertise on muscle timing.

Convergent kinematic and postural findings reinforce the timing interpretation. Akbaş et al. (2021) identified earlier anticipatory postural adjustments before the lunge, while Borysiuk et al. (2018) reported perception-dependent differences in the flèche and Borysiuk et al. (2019) reported greater competition effectiveness for flèche than lunge under the studied conditions. Gutiérrez-Davila et al. (2016) further showed that defensive responses are slower to feints than direct attacks, highlighting the cost of deceptive information. Wheelchair-fencing findings (Borysiuk et al., 2020) indicate that disability category alters movement organisation and therefore limits direct extrapolation from able-bodied fencing.

Findings for RQ2 - Perceptual-cognitive processes and neural correlates

Seven empirical studies and one narrative review addressed perceptual-cognitive and neural correlates. Reaction-time evidence shows that stimulus modality influences response speed and that experienced fencers generally respond faster across tested conditions (Borysiuk & Bailey, 2007; Borysiuk, 2008). Williams and Walmsley (2000b) found superior online response amendment in elite fencers, while Zhang et al. (2015) reported stronger response inhibition in experienced fencers. EEG/ERP studies provide convergent evidence for anticipatory and executive preparation: Bianco et al. (2017) reported stronger proactive cortical control in fencers, and Taddei et al. (2012) observed preserved attentional and executive ERP characteristics in middle-aged fencers.

The eye-tracking evidence is more limited. Babadi et al. (2021) found that expert fencing referees used fewer, longer fixations while achieving higher decision accuracy than novice referees. Borysiuk (2025) synthesised related combat-sport evidence and proposed perceptual-training implications, but this review is contextual rather than a new empirical fencing sample. Direct, simultaneous measurement of gaze during authentic fencing exchanges remains rare, so the current evidence cannot establish a direct pathway from visual fixation to muscle preparation. Future multimodal studies should therefore test ocular, neural, and neuromuscular signals within the same fencing task.

Findings for RQ3 - Training and technological interventions

Three reports addressed training or technology-related questions. Teteris et al. (2025) reported improved choice reaction time after a 12-week training programme in U20 fencers, providing preliminary longitudinal evidence for trainability. Barañano-Alcaide et al. (2025) found slower reaction time following fencing-related physical and mental fatigue, suggesting that training load and readiness can influence decision speed. Borysiuk and Waśkiewicz (2008) proposed multisensory perceptual training from an information-processing perspective. By contrast, virtual-reality and AI applications remain preliminary within fencing: related technologies are discussed in the literature, but no included empirical fencing study evaluated an AI-based system, and the cited 2026 VR work is a protocol rather than an outcome study.

Comparative and Critical Analysis

The comparative synthesis incorporated 19 empirical reports spanning reaction time/EMG, EEG/ERP, kinematics and ground-reaction forces, posturography, eye-tracking, fatigue, and training paradigms (Williams & Walmsley, 2000a, 2000b; Borysiuk & Bailey, 2007; Borysiuk, 2008; Taddei et al., 2012; Zhang et al., 2015; Balkó et al., 2016; Gutiérrez-Davila et al., 2016; Bianco et al., 2017; Balkó et al., 2018; Borysiuk et al., 2018, 2019, 2020, 2022a, 2024; Babadi et al., 2021; Akbaş et al., 2021; Kim et al., 2023; Barañano-Alcaide et al., 2025; Teteris et al., 2025). The framework was applied only when a report directly examined fencing participants or directly analysed fencing performance. Narrative reviews were used for conceptual context but not counted as empirical confirmation. Across these studies, the strongest convergence is around earlier preparation and efficient response control; evidence for gaze and intervention effects is more tentative.

Discussion

Taken together, the evidence supports a multimodal account of fencing expertise: anticipation is expressed through earlier and better-organised muscle recruitment, efficient visual search, faster or more stable response control, and proactive cortical preparation. These domains should be regarded as correlated components of a perception-action system rather than as independent causal determinants. The evidence is strongest for expertise contrasts in laboratory or controlled fencing tasks and weakest for causal claims about long-term learning or competitive transfer.

The findings extend perception-action models of combat-sport expertise (De Quel & Bennett, 2019) by showing that anticipatory control can be indexed at several measurable levels. The observed EMG-GRF lead reported by Borysiuk et al. (2024) is consistent with a preparatory feedforward interpretation, while the EEG/ERP literature suggests that central preparation also differentiates experienced performers. These links remain inferential because simultaneous multimodal recordings during live fencing are scarce.

For practice, coaches should emphasise multisensory perceptual and reaction training, monitor fatigue-related slowing, and use sensor feedback cautiously as an adjunct rather than a substitute for performance judgement. The present evidence supports EMG, force, gaze, and reaction-time measures as potentially informative indicators, but their reliability and transfer to competition have not been demonstrated uniformly across studies. The 12-week pilot provides preliminary support for trainability, not definitive evidence of durable transfer.

The principal contribution of this review is methodological integration: it places 21 empirical studies within one framework while preserving differences between neuromuscular, cognitive, ocular, and neural outcomes. This approach avoids treating all measures as interchangeable and makes the evidence gaps more explicit. In particular, there is a clear asymmetry between the relatively mature EMG/reaction-time literature and the much smaller evidence base for ecological eye-tracking, synchronized neural recording, and technology-assisted interventions.

Boundary conditions and generalizability require explicit caution. Most evidence comes from small, selected samples of competitive fencers, often comparing elite or experienced athletes with novices under controlled conditions. Weapon type, task structure, fatigue state, disability category, sex, age, and competitive context are not uniformly represented. Wheelchair-fencing studies cannot be assumed to replicate the neuromuscular organisation of able-bodied fencing, and referee gaze behaviour cannot be treated as equivalent to a fencer's gaze during attack or defence. Measurement reliability also differs across EMG, EEG/ERP, force, kinematic, and eye-tracking protocols, limiting direct cross-study comparability.

Three substantive evidence gaps remain. First, direct eye-tracking during authentic fencing exchanges is rare, leaving the visual basis of anticipation incompletely specified. Second, longitudinal and randomised intervention studies remain scarce, so the trainability and transferability of anticipation and decision-making cannot yet be estimated with high confidence. Third, although AI and computer-vision methods are increasingly discussed in sport, no included empirical fencing study evaluated an AI-based system for anticipation, decision-making, or officiating. These gaps define priorities for future work rather than established capabilities of current technology.

Several methodological limitations of the review also affect interpretation. The search was restricted to three databases and English-language publications, which can omit relevant studies. The corpus is geographically concentrated, with nine reports from Poland and many neuromuscular studies originating from one research group, raising concerns about independent replication. The inclusion of heterogeneous designs prevented defensible quantitative pooling, and the original screening process did not preserve two-rater decisions, so Cohen's kappa could not be computed retrospectively. The absence of a verified, non-overlapping participant denominator also means that an aggregate N would risk double counting participants from related cohorts. These limitations are reported explicitly rather than replaced by reconstructed statistics.

Future studies should synchronise EMG, force or pressure, kinematics, gaze, and EEG during representative fencing actions; use multisite samples and preregistered longitudinal or randomised designs; and report sufficient statistics for effect-size calculation. Where interventions are studied, researchers should distinguish immediate reaction-time gains from transfer to opponent-based decision-making and competition. Machine-learning approaches should also be evaluated for predictive validity, interpretability, fairness, and human autonomy before being proposed as coaching or officiating systems.

In direct response to the research questions, RQ1 is supported by convergent evidence that expertise is associated with earlier preparatory muscle activation, more efficient EMG coordination, and altered postural or force regulation. RQ2 is supported by evidence for faster response control, stronger inhibition, more efficient gaze behaviour, and greater proactive cortical preparation. RQ3 is supported only preliminarily: reaction-time training and fatigue monitoring show actionable associations, while evidence for VR and AI in fencing remains insufficient for strong effectiveness claims. These conclusions are deliberately framed at the level of association and evidence strength rather than causality.

Conclusions

This PRISMA 2020 review of 22 reports (21 empirical studies and one narrative review used for context) indicates that fencing anticipation and decision-making are distributed across neuromuscular, perceptual-cognitive, ocular, and neural processes. The most consistent empirical pattern is that higher expertise is associated with earlier preparatory activation, more efficient muscular coordination, faster or more stable response control, and stronger proactive preparation. Evidence for efficient gaze behaviour is promising but sparse, and intervention evidence is still preliminary. The criterion-level MMAT appraisal showed generally strong reporting with some partial or unclear judgments; these appraisal findings were used to temper interpretation rather than to exclude studies by an arbitrary total score. No quantitative meta-analysis or forest plot was produced because outcome definitions, tasks, and reported statistics were insufficiently compatible for defensible pooling. A structured narrative synthesis consistent with SWiM principles was therefore used, with explicit rules for handling conflicting evidence. The review is limited by small and heterogeneous samples, predominantly cross-sectional designs, restricted database and language coverage, geographic and laboratory concentration, scarce real-world multimodal recording, absence of a verified aggregate participant denominator, and lack of retrospective inter-rater kappa data. Future research should prioritise multisite replication, longitudinal and randomised intervention studies, simultaneous EMG-force-kinematics-gaze-EEG measurement, and appropriately reported effect sizes. AI-based analysis should be evaluated empirically rather than treated as an established capability. Overall, current evidence supports a multimodal framework for fencing expertise, but not a single causal mechanism.

Acknowledgments

The Authors would like to thank Faculty of Sport Sciences, Universitas Negeri Padang for providing excellent facilities, as well as for being very supportive of this research from the beginning. Authors also thank the team members who had generously shared their brilliant ideas, engaging discussion, and academic supports during the study.

References

Akbaş, A., Marszałek, W., Bacik, B., & Juras, G. (2021). Two Aspects of Feedforward Control During a Fencing Lunge: Early and Anticipatory Postural Adjustments. Frontiers in Human Neuroscience, 15, Article 638675. https://doi.org/10.3389/fnhum.2021.638675

Babadi, N., Abdoli, B., Farsi, A., & Moeinirad, S. (2021). Comparison of Visual Search Behavior and Decision-making Accuracy in Expert and Novice Fencing Referees. Optometry and Vision Science, 98(7), 783–788. https://doi.org/10.1097/OPX.0000000000001726

Balkó, Š., Borysiuk, Z., Balkó, I., & Špulák, D. (2016). The influence of different performance level of fencers on muscular coordination and reaction time during the fencing lunge. Archives of Budo, 12, 49–59. Available from: https://archivesofbudo.com/

Balkó, Š., Heidler, J., & Jelínek, M. (2018). Relationship between the armed arm's motor response and muscle activation time during the lunge in fencers of varied ability. Journal of Human Sport and Exercise, 13(1), 50–59. https://doi.org/10.14198/jhse.2018.131.06

Barañano-Alcaide, R., Sillero-Quintana, M., Bernardez-Vilaboa, R., Barañano-Perez, J., Gonzalez-Jiménez, R., & Navarro-Barragán, R. M. (2025). Analysis of the effect of fatigue in fencing using reaction time lights. Revista Brasileira de Cineantropometria e Desempenho Humano, 27(1), Article e107404. https://doi.org/10.1590/1980-0037.2025v27e107404

Bian, C., Russell, S., De Pauw, K., Kons, R., Grosprêtre, S., Bogataj, Š., & Roelands, B. (2026). Comparing embedded virtual reality combat to traditional warm-ups on fencing performance and fatigue: Protocol for a randomized crossover trial. JSAMS Plus, 8, Article 100144. https://doi.org/10.1016/j.jsampl.2026.100144

Bianco, V., Di Russo, F., Perri, R. L., & Berchicci, M. (2017). Different proactive and reactive action control in fencers' and boxers' brain. Neuroscience, 343, 260–268. https://doi.org/10.1016/j.neuroscience.2016.12.006

Borysiuk, Z., & Bailey, R. (2007). Influence of stimuli type on electromyography (EMG) signal, reaction and movement time in novice and advanced fencers. Journal of Human Movement Studies, 52(2), 65–79.

Borysiuk, Z., & Waskiewicz, Z. (2008). Information Processes, Stimulation and Perceptual Training in Fencing. Journal of Human Kinetics, 19, 63–82. https://doi.org/10.2478/v10078-008-0005-y

Borysiuk, Z. (2008). Psychomotor reactions in fencing dependence of stimuli type. Revista Brasileira de Cineantropometria e Desempenho Humano, 10(3), 223–229. https://doi.org/10.5007/1980-0037.2008v10n3p223

Borysiuk, Z., Markowska, N., Czyż, S., Konieczny, M., Pakosz, P., & Kręcisz, K. (2018). Fencing Flèche performed by elite and novice épéeists depending on type of perception. Archives of Budo, 14, 179–187.

Borysiuk, Z., Markowska, N., Konieczny, M., Kręcisz, K., Błaszczyszyn, M., Nikolaidis, P. T., Knechtle, B., & Pakosz, P. (2019). Flèche versus lunge as the optimal footwork technique in fencing. International Journal of Environmental Research and Public Health, 16(13), Article 2315. https://doi.org/10.3390/ijerph16132315

Borysiuk, Z., Nowicki, T., Piechota, K., & Błaszczyszyn, M. (2020). Neuromuscular, Perceptual, and Temporal Determinants of Movement Patterns in Wheelchair Fencing: Preliminary Study. BioMed Research International, 2020, Article 6584832. https://doi.org/10.1155/2020/6584832

Borysiuk, Z., Błaszczyszyn, M., Piechota, K., Balko, S., & Waśkiewicz, Z. (2022a). EMG structure, ground reaction forces as anticipatory indicators of the fencing lunge effectiveness. Archives of Budo, 18, 13–22.

Borysiuk, Z., Błaszczyszyn, M., Piechota, K., & Nowicki, T. (2022b). Movement Patterns of Polish National Paralympic Team Wheelchair Fencers with Regard to Muscle Activity and Co-Activation Time. Journal of Human Kinetics, 82(1), 223–232. https://doi.org/10.2478/hukin-2022-0064

Borysiuk, Z., Blaszczyszyn, M., Piechota, K., Konieczny, M., & Cynarski, W. J. (2023). Correlations between the EMG Structure of Movement Patterns and Activity of Postural Muscles in Able-Bodied and Wheelchair Fencers. Sensors, 23(1), Article 135. https://doi.org/10.3390/s23010135

Borysiuk, Z., Konieczny, M., Błaszczyszyn, M., Błach, W., & Obmiński, Z. (2024). The phenomenon of anticipation in fencing. An applicability approach. Frontiers in Sports and Active Living, 6, Article 1387013. https://doi.org/10.3389/fspor.2024.1387013

Borysiuk, Z. (2025). Eye-Tracking Analysis of Perceptual-Cognitive Processes in Combat Sports: A Narrative Review. Ido Movement for Culture, 25(3), 89–95. https://doi.org/10.14589/ido.25.3.10

Borysiuk, Z., Błaszczyszyn, M., Piechota, K., & Akbaş, A. (2025). Are technical performance differences in wheelchair fencing linked to disability categories. BMC Sports Science, Medicine and Rehabilitation, 17(1), Article 23. https://doi.org/10.1186/s13102-025-01071-z

Campbell, M., McKenzie, J. E., Sowden, A., Katikireddi, S. V., Brennan, S. E., Ellis, S., Hartmann-Boyce, J., Ryan, R., Shepperd, S., Thomas, J., Welch, V., & Thomson, H. (2020). Synthesis without meta-analysis (SWiM) in systematic review reporting guideline. BMJ, 368, l6890. https://doi.org/10.1136/bmj.l6890

Ceyte, H., Lion, A., Caudron, S., Perrin, P., & Gauchard, G. C. (2017). Visuo-oculomotor skills related to the visual demands of sporting environments. Experimental Brain Research, 235(1), 269–277. https://doi.org/10.1007/s00221-016-4793-3

De Quel, Ó. M., & Bennett, S. J. (2019). Perceptual-cognitive expertise in combat sports: A narrative review and a model of perception-action. RICYDE: Revista Internacional de Ciencias del Deporte, 15(58), 323–338. https://doi.org/10.5232/ricyde2019.05802

Del Percio, C., Brancucci, A., Vecchio, F., Marzano, N., Pirritano, M., Meccariello, E., Padoa, S., Mascia, A., Giallonardo, A. T., Aschieri, P., Lino, A., Palma, E., Fiore, A., Di Ciolo, E., Babiloni, C., & Eusebi, F. (2007). Visual event-related potentials in elite and amateur athletes. Brain Research Bulletin, 74(1-3), 104–112. https://doi.org/10.1016/j.brainresbull.2007.05.011

Del Percio, C., Rossini, P. M., Marzano, N., Iacoboni, M., Infarinato, F., Aschieri, P., Lino, A., Fiore, A., Toran, G., Babiloni, C., & Eusebi, F. (2008). Is there a "neural efficiency" in athletes? A high-resolution EEG study. NeuroImage, 42(4), 1544–1553. https://doi.org/10.1016/j.neuroimage.2008.05.061

Guizani, S. M., Bouzaouach, I., Tenenbaum, G., Ben Kheder, A., Feki, Y., & Bouaziz, M. (2006). Simple and choice reaction times under varying levels of physical load in high skilled fencers. Journal of Sports Medicine and Physical Fitness, 46(2), 344–351.

Gutiérrez-Davila, M., Rojas, F. J., Gutiérrez-Cruz, C., García, C., & Navarro, E. (2016). Time required to initiate a defensive reaction to direct and feint attacks in fencing. Journal of Applied Biomechanics, 32(6), 548–552. https://doi.org/10.1123/jab.2015-0333

Hong, Q. N., Pluye, P., Bujold, M., & Vedel, I. (2018). Mixed Methods Appraisal Tool (MMAT), version 2018. Registration of Copyright (#1148552), Canadian Intellectual Property Office, Industry Canada.

Imperiali, L., Codella, R., Bizzozero, S., La Torre, A., Buratti, M., & Borghi, S. (2026). Lateral Dominance and Cognitive–Motor Performance in Elite Athletes: A Virtual Reality Study. Perceptual and Motor Skills. https://doi.org/10.1177/00315125261456961

Kim, T. W., Lee, J. S., & Jo, I. (2023). Low Activation of Knee Extensors and High Activation of Knee Flexors in Female Fencing Athletes Is Related to the Response Time during the Marche-Fente. International Journal of Environmental Research and Public Health, 20(1), Article 17. https://doi.org/10.3390/ijerph20010017

Liberati, A., Altman, D. G., Tetzlaff, J., Mulrow, C., Gøtzsche, P. C., Ioannidis, J. P. A., Clarke, M., Devereaux, P. J., Kleijnen, J., & Moher, D. (2009). The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions. BMJ, 339, b2700. https://doi.org/10.1136/bmj.b2700

Mak, H. Y., Lin, Q., Tzeng, O. J., & Huang, H. W. (2025). EEG insights into predictive coding of temporal regularity in shape sequences. Biological Psychology, 202, Article 109143. https://doi.org/10.1016/j.biopsycho.2025.109143

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. BMJ, 372, n71. https://doi.org/10.1136/bmj.n71

Rowlatt, G., Bottoms, L., Edmonds, C., & Buscombe, R. (2017). The effect of carbohydrate mouth rinsing on fencing performance and cognitive function following fatigue-inducing fencing. European Journal of Sport Science, 17(4), 433–440. https://doi.org/10.1080/17461391.2016.1251497

Rutkowski, S., Jakóbczyk, A., Abrahamek, K., Nowakowska, A., Nowak, M., Liska, D., Batalik, L., Colombo, V., & Sacco, M. (2024). Training using a commercial immersive virtual reality system on hand–eye coordination and reaction time in students: a randomized controlled trial. Virtual Reality, 28(1), Article 7. https://doi.org/10.1007/s10055-023-00898-6

Taddei, F., Bultrini, A., Spinelli, D., & Di Russo, F. (2012). Neural correlates of attentional and executive processing in middle-age fencers. Medicine and Science in Sports and Exercise, 44(6), 1057–1066. https://doi.org/10.1249/MSS.0b013e31824529c2

Teteris, L. E., Saulite, S., Licis, R., Greve, M., & Boobani, B. (2025). Application of the Vienna Test System to Measure Training-Induced Changes in Choice Reaction Time in U20 Fencers: A 12-Week Training Program Pilot Study. Sports, 13(11), Article 400. https://doi.org/10.3390/sports13110400

Thomas, J., & Harden, A. (2008). Methods for the thematic synthesis of qualitative research in systematic reviews. BMC Medical Research Methodology, 8, 45. https://doi.org/10.1186/1471-2288-8-45

Tosti, B., Corrado, S., Mancone, S., Di Libero, T., Carissimo, C., Cerro, G., Rodio, A., da Silva, V. F., Coimbra, D. R., Andrade, A., & Diotaiuti, P. (2024). Neurofeedback Training Protocols in Sports: A Systematic Review of Recent Advances in Performance, Anxiety, and Emotional Regulation. Brain Sciences, 14(10), Article 1036. https://doi.org/10.3390/brainsci14101036

Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a methodology for developing evidence-informed management knowledge by means of systematic review. British Journal of Management, 14(3), 207–222. https://doi.org/10.1111/1467-8551.00375

Vuorinen, N., & Loland, S. (2025). AI, Performance Enhancement and Agential Limits: A Functionalist Evaluation Framework. Artificial Intelligence and Neuroenhancement in Sport, 70–88. https://doi.org/10.4324/9781003520290-5

Williams, L., & Walmsley, A. (2000a). Response timing and muscular coordination fencing: A comparison of elite and novice fencers. Journal of Science and Medicine in Sport, 3(4), 460–475. https://doi.org/10.1016/S1440-2440(00)80011-0

Williams, L., & Walmsley, A. (2000b). Response amendment in fencing: Differences between elite and novice subjects. Perceptual and Motor Skills, 91(1), 131–142. https://doi.org/10.2466/pms.2000.91.1.131

Zhang, D., Ding, H., Wang, X., Qi, C., & Luo, Y. (2015). Enhanced response inhibition in experienced fencers. Scientific Reports, 5, Article 16282. https://doi.org/10.1038/srep16282