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Neuromuscular coordination and motor adaptability in the fencing lunge and attack: a PRISMA 2020-guided systematic review

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ABSTRACT

Competitive fencing is a rapid, open-skill combat sport in which offensive success depends on precise organisation, timing, and adaptability of whole-body movement rather than speed alone. This systematic review synthesised empirical evidence on neuromuscular coordination, movement variability, and motor adaptability during fencing lunges and attacks. The review followed PRISMA 2020 and used PICOS-based eligibility criteria for English-language, peer-reviewed empirical quantitative studies of competitive fencers, including able-bodied and wheelchair fencers, that examined movement, motor control, coordination, or adaptability of the lunge/attack. Searches of Scopus, PubMed, and ScienceDirect identified 712 records published across 2000-2026; 20 studies were included after screening and full-text assessment. Study quality was appraised with the Mixed Methods Appraisal Tool (MMAT) 2018. Because the included studies were heterogeneous in population, weapon, task, measurement, and outcome, findings were synthesised narratively using thematic coding rather than quantitative meta-analysis. Across the corpus, expertise was associated with earlier anticipatory and postural adjustments, more efficient muscular sequencing, greater rear-leg propulsion, and stronger capacity to correct ongoing actions under uncertainty. Movement variability appears functional rather than merely error, but standardised variability metrics are lacking. Future research should prioritise longitudinal and intervention designs, broader para-fencing evidence, and standardised biomechanical reporting.

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Introduction

Fencing has long served as a model for examining high-speed, open-skill motor behaviour. During competition, success depends on perceiving relevant information, selecting an appropriate response, and executing that response rapidly while maintaining dynamic postural control on the piste (Chen et al., 2017).

The lunge is a primary offensive technique in fencing. It combines extension of the armed arm and lower-limb propulsion while preserving sufficient postural control for subsequent actions. Its effectiveness depends on the coordination of arm motion, rear-leg propulsion, and postural stabilisation (Guan et al., 2018; Guilhem et al., 2014). Research on attack execution also indicates that meaningful changes in speed, accuracy, and deception can arise without large changes in the overall order of segmental activation or foot placement.

A substantial body of research has described physical, perceptual, and motor characteristics associated with fencing performance, including anthropometric and physiological profiles (Tsolakis & Vagenas, 2010), lower-limb power and change-of-direction speed (Turner et al., 2016), and response timing under different levels of choice and uncertainty (Gutiérrez-Dávila et al., 2013b; Gutiérrez-Dávila et al., 2016). Training, feedback, and practice scheduling have also been examined as potential influences on motor performance (Balkó et al., 2017; Bayyat & AlKayeed, 2024). Together, these studies indicate that fencing performance emerges from interacting physical, perceptual, and motor-control processes.

Methodological advances now allow fencing movement to be examined in greater detail. Three-dimensional motion analysis, surface electromyography (EMG), force platforms, inertial measurement units, and validated two-dimensional video approaches have been used to quantify kinematics, kinetics, muscle activity, and movement organisation (Frère et al., 2011; Chida et al., 2024; Mahdi et al., 2026). These methods have shifted attention from outcome speed alone toward the organisation and variability of movement and therefore provide a basis for examining motor adaptability.

The evidence base nevertheless remains fragmented. Studies differ in weapon type (foil, épée, or sabre), population (able-bodied and wheelchair fencers), skill level, task constraints, and outcome definitions, which limits direct cumulative comparison. Movement variability is particularly important because contemporary motor-control perspectives treat variability as a potential resource for flexible adaptation rather than simply as noise. The unresolved question is therefore how neuromuscular coordination, movement organisation, and adaptability vary with expertise and task constraints.

A further theoretical and methodological gap concerns the predominance of cross-sectional, descriptive designs. Many studies compare skilled and less-skilled fencers at a single time point, whereas fewer examine how movement organisation changes online in response to uncertainty or target changes. Information-processing, dynamical-systems, and feedforward-control perspectives are rarely integrated explicitly, limiting the translation of findings into coherent coaching strategies.

A systematic review is warranted to integrate this heterogeneous literature and identify evidence-supported determinants of attack performance. Accordingly, this review synthesises empirical work on neuromuscular coordination, movement adaptability, and technical determinants of the fencing lunge and attack, while explicitly considering methodological quality and evidence gaps.

We addressed three research questions. The first examined skill-related differences in neuromuscular organisation; the second focused on mechanisms of motor adaptability under uncertainty and target change; and the third identified movement and technique factors associated with attack effectiveness.

RQ1: How do neuromuscular coordination and movement organisation differ in the fencing lunge and attack between different skill levels?

The second question concerned adaptability, defined as the ability to modify an ongoing or planned action in response to uncertainty, target change, or altered task constraints.

RQ2: What kinematic, kinetic, and postural-control mechanisms support motor adaptability during fencing attacks?

The third question addressed technically modifiable factors that may influence attack effectiveness. Because most included studies were observational or non-randomised, the review focuses on factors associated with performance rather than causal determinants.

RQ3: Which movement and technique factors, including base of support, foot placement, weapon control, and feedforward motor control, are associated with the effectiveness of the fencing lunge and attack?

Method

The review used a systematic literature review design guided by PRISMA 2020 (Page et al., 2021). The protocol and reporting structure were defined around the PICOS framework. No meta-analysis was undertaken because the included studies were heterogeneous in participants, weapons, tasks, measurement approaches, and reported outcomes. No protocol-registration record is reported in the manuscript; this should be verified against the authors' study documentation before submission.

Review protocol and reproducibility

The review question was decomposed using PICOS (Population, Intervention/Interest, Comparison, Outcome, Study design) before constructing the search strategy. The search was designed to capture fencing, lunge/attack, motor-control, coordination, biomechanics, reaction, postural, and variability concepts while limiting clearly unrelated uses of homonymous terms.

Population (P): competitive fencers using foil, épée, or sabre, including able-bodied and wheelchair fencers across reported skill levels.

Intervention/Interest (I): fencing lunge or attack performed under controlled or competitive/task-constrained conditions.

Comparison (C): skill level and/or task constraint, including target condition, stance or foot positioning, and weapon where relevant. No single comparator was required across all studies because this was a heterogeneous observational evidence base.

Outcome (O): movement variability; neuromuscular/muscular coordination; kinematics and kinetics; reaction/response timing; postural balance or control during attack; and attack effectiveness or accuracy.

Study design (S): peer-reviewed empirical quantitative studies, including descriptive, non-randomised, kinematic, EMG, force-platform, inertial-sensor, and observational designs. Narrative reviews, consensus papers, and pure modelling studies without empirical data were excluded.

Each PICOS element contributed synonyms that were combined with Boolean operators. Searches were applied to title, abstract, and keyword fields where supported by the database. The final search string was:

Truncation and wildcards were used to capture morphological variants. The use of a homonym filter was restricted to records whose titles/abstracts clearly indicated non-sport uses of fencing, foil, lunge, or variability; these records were treated as pre-screening exclusions and were not entered into manual title/abstract screening.

("fencing" OR "fencer" OR "épée" OR "epee" OR "foil" OR "sabre" OR "saber") AND ("lunge" OR "attack" OR "flèche" OR "riposte" OR "movement" OR "motor control" OR "coordination" OR "kinematic*" OR "biomechanic*" OR "electromyograph*" OR "postural" OR "reaction time" OR "movement variability") AND ("elite" OR "novice" OR "skill*" OR "performance" OR "adapt*" OR "expertise")*

Three databases were searched: Scopus, PubMed, and ScienceDirect. The combined search yielded 712 records (Scopus n = 207; PubMed n = 405; ScienceDirect n = 100). The database search date should be inserted from the original export before submission; the manuscript currently documents only the publication-year range represented in the final corpus (2000-2026).

Database and Information Sources

Eligibility Criteria

Study selection followed PRISMA 2020. From the 712 retrieved records, 587 were removed before formal screening because titles/abstracts clearly indicated non-sport or otherwise out-of-scope uses of the search terms, and 20 duplicate records were removed. The remaining 105 records were screened by title and abstract; 75 were excluded as irrelevant to movement or motor control. Thirty reports were sought for full-text retrieval; two were not retrieved. Twenty-eight reports were assessed for eligibility, of which eight were excluded (four without a motor-specific outcome, three non-empirical studies, and one non-fencing sample). Twenty studies were included in the synthesis. The manuscript does not contain a screening log or inter-rater agreement statistic; no Cohen's kappa is therefore claimed without source documentation.

Table 1. Inclusion and exclusion criteria applied during study selection

Criterion	Inclusion	Exclusion
Language	English	Non-English
Document type	Peer-reviewed journal article (empirical)	Conference paper, book chapter, editorial, thesis
Population	Competitive fencers (any weapon; able-bodied or wheelchair)	Non-fencing samples; fencing only as an incidental example
Focus	Movement, motor control, coordination, or adaptability of the lunge/attack	Injury/rehabilitation, psychology, or physiology without a movement outcome
Study design	Empirical quantitative (descriptive/non-randomised, kinematic/EMG, observational)	Narrative reviews, Delphi/consensus, pure modelling without data
Accessibility	Full text retrievable	Abstract only / not retrievable

Criterion	Inclusion	Exclusion
Relevance	Directly addresses a movement/motor-control question in fencing	Tangential or homonym (non-sport "fencing/foil") records

Quality Assessment

Study quality was assessed with the Mixed Methods Appraisal Tool (MMAT), version 2018 (Hong et al., 2018). Each study was rated on the five criteria relevant to its design using 1.0 (met), 0.5 (partially met/cannot tell), or 0.0 (not met). The resulting scores were used descriptively and not as an automatic exclusion threshold. This approach is reported transparently because the included corpus is dominated by descriptive and non-randomised quantitative studies.

Table 2. Methodological quality appraisal of included studies using the MMAT 2018 (0 = not met; 0.5 = can't tell/partial; 1 = met).

Author(s), Year	Design	Q1	Q2	Q3	Q4	Q5	Score	Quality
Guilhem et al. (2014)	Quant. descriptive	1	1	1	0.5	1	4.5	High (90%)
Plantard et al. (2017)	Quant. descriptive (pilot)	0.5	0.5	1	0.5	0.5	3	Medium (60%)
Akbaş et al. (2021)	Quant. non-randomised	1	1	1	1	1	5	High (100%)
Akbaş et al. (2024)	Quant. descriptive	1	1	1	0.5	1	4.5	High (90%)
Guan et al. (2018)	Quant. non-randomised	1	1	1	1	1	5	High (100%)
Frère et al. (2011)	Quant. descriptive	1	1	0.5	1	1	4.5	High (90%)
Balkó et al. (2018)	Quant. non-randomised	1	1	1	0.5	1	4.5	High (90%)
Borysiuk et al. (2022)	Quant. descriptive	0.5	1	0.5	0.5	1	3.5	Medium (70%)
Balkó et al. (2016)	Quant. non-randomised	1	1	1	0.5	1	4.5	High (90%)
Williams & Walmsley (2000)	Quant. non-randomised	1	1	0.5	1	1	4.5	High (90%)
Zeuwts et al. (2017)	Quant. descriptive	1	1	1	1	1	5	High (100%)
Gutiérrez-Dávila et al. (2014)	Quant. descriptive	1	1	1	1	0.5	4.5	High (90%)
Gutiérrez-Dávila et al. (2013)	Quant. non-randomised	1	1	1	1	1	5	High (100%)
Herpin et al. (2010)	Quant. non-randomised	1	1	1	0.5	1	4.5	High (90%)
Mahdi et al. (2026)	Quant. descriptive	1	0.5	1	0.5	1	4	High (80%)
Nikolov et al. (2024)	Quant. descriptive	0.5	1	0.5	1	1	4	High (80%)
Dedieu et al. (2024)	Quant. non-randomised	1	1	1	1	1	5	High (100%)
Gresham-Fiegel et al. (2013)	Quant. non-randomised	1	1	1	0.5	1	4.5	High (90%)
Krzykała et al. (2023)	Quant. descriptive	1	1	1	1	0.5	4.5	High (90%)
Chida et al. (2024)	Quant. descriptive (validation)	1	1	1	1	1	5	High (100%)

Data Extraction Procedure

For each included study, the following data were extracted directly from the source records and full texts: author(s), year, journal, study design, sample (size, sex, weapon, and skill level where reported), task or condition, measurement method, primary movement/motor outcome, and key findings. Extraction was recorded in a structured matrix that formed the basis for Tables 3 and 4.

Bibliometric Characterisation

Temporal publication trends and author-keyword frequencies were summarised descriptively from exported metadata. This bibliometric step provided context for the corpus and was not used to derive substantive effect estimates.

Data Analysis and Synthesis

Because the included studies were methodologically heterogeneous and reported diverse outcomes, a narrative thematic synthesis was undertaken following the thematic-synthesis approach of Thomas and Harden (2008). Findings were coded, grouped by research question, and compared for convergence, divergence, and evidence gaps. Quantitative pooling was not attempted because outcome definitions, tasks, measurement protocols, and participant groups were not sufficiently comparable.

Reporting and Documentation

The review was reported in accordance with PRISMA 2020 (Page et al., 2021). All quantitative claims in the Results and thematic synthesis are traceable to the included studies and the extracted evidence matrix.

Study Selection Flow (PRISMA 2020)

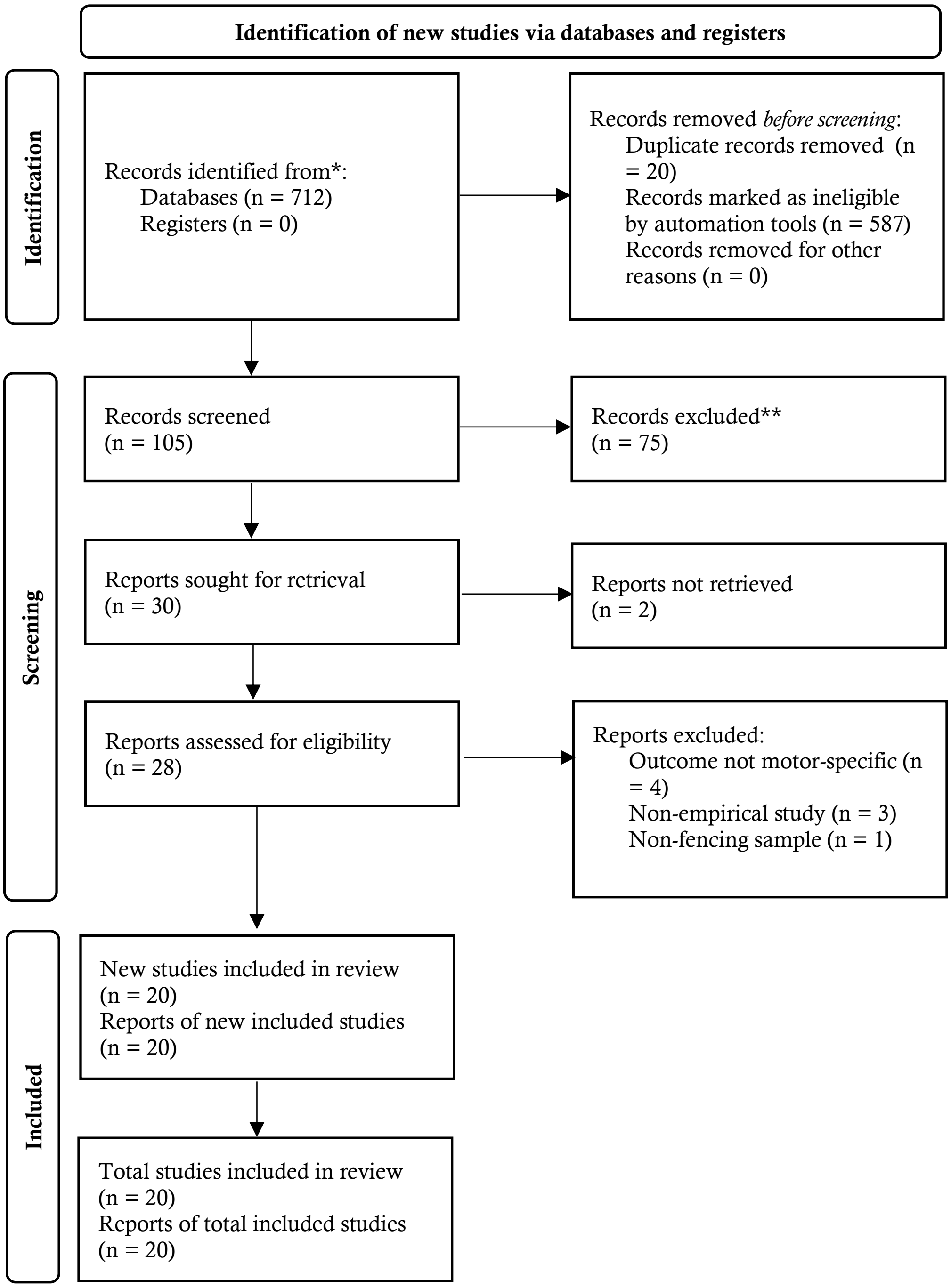

Figure 1. PRISMA 2020 flow diagram of the study selection process. Numbers are derived from the combined database search across Scopus, PubMed, and ScienceDirect (Page et al., 2021).

Results and Discussions

Results of Study Selection

The searches identified 712 records: Scopus (n = 207), PubMed (n = 405), and ScienceDirect (n = 100). A pre-screening topical filter removed 587 clearly off-topic records, followed by removal of 20 duplicates. The remaining 105 records underwent title/abstract screening, of which 75 were excluded. Thirty reports were sought for retrieval; two full texts were unavailable. Twenty-eight reports underwent full-text eligibility assessment, and eight were excluded (four without motor-specific outcomes, three non-empirical reports, and one non-fencing sample). The final synthesis therefore comprised 20 studies.

Descriptive characteristics

The 20 included studies were published between 2000 and 2026 in sport-science, biomechanics, and motor-control journals. The corpus covered foil, épée, and sabre and included able-bodied and wheelchair fencers. Common measurement approaches were three-dimensional motion capture, surface EMG, force platforms, inertial sensors, and validated two-dimensional video analysis. Detailed study-level characteristics are presented in Tables 3 and 4.

Table 3. Summary of the 20 included studies with full titles and key findings.

Title	Author(s), Year	Journal	Key Findings
Mechanical and muscular coordination patterns during a high-level fencing assault	Guilhem et al., 2014	Medicine and Science in Sports and Exercise	Lower-limb muscular coordination during the maré-fente is linked to the mechanical effectiveness of the attack; elite sabre fencers show organised, effectiveness-related muscle coordination and inter-leg torque profiles.
Motion adaptation in fencing lunges: a pilot study	Plantard et al., 2017	Computer Methods in Biomechanics and Biomedical Engineering	Pilot study proposing a motion-capture and modelling approach to characterise motion-adaptation strategies in the fencing lunge (quantitative findings not reported in the source abstract).
Two Aspects of Feedforward Control During a Fencing Lunge: Early and Anticipatory Postural Adjustments	Akbaş et al., 2021	Frontiers in Human Neuroscience	Expertise advances feedforward postural control: elite fencers initiate anticipatory and early postural adjustments earlier than students, and onset varies with stance width and self-paced vs. reaction-time conditions.
Influence of base of support on early postural adjustments and fencing lunge performance	Akbaş et al., 2024	Sports Biomechanics	The width of the base of support modulates early postural adjustments and armed-limb and centre-of-mass kinematics during lunging in elite female fencers.
Biomechanical insights into the determinants of speed in the fencing lunge	Guan et al., 2018	European Journal of Sport Science	Elite fencers achieve higher horizontal centre-of-gravity velocity and higher rear-leg peak ground reaction force than intermediates, identifying rear-leg propulsion as a key determinant of lunge speed.
Kinematical and EMG-classifications of a fencing attack	Frère et al., 2011	International Journal of Sports Medicine	Three-dimensional kinematics with wavelet-based EMG classifies flèche attacks into distinct temporal muscle-activation patterns that differentiate fencer groups.
Relationship between the armed arm's motor response and muscle activation time during the lunge in fencers of varied ability	Balkó et al., 2018	Journal of Human Sport and Exercise	Muscle-activation timing of the armed arm during the lunge differs between elite and beginner épée fencers, indicating skill-related neuromuscular organisation.
EMG structure, ground reaction forces as anticipatory indicators of the fencing lunge effectiveness	Borysiuk et al., 2022	Archives of Budo	EMG onset precedes vertical ground reaction force; anticipatory muscle activation and force timing serve as indicators of épée straight-lunge effectiveness.
The influence of different performance level of fencers on muscular coordination and reaction time during the fencing lunge	Balkó et al., 2016	Archives of Budo	Higher-level fencers display shorter reaction times and distinct muscular-coordination timing during the lunge relative to lower-level fencers.
Response timing and muscular coordination	Williams & Walmsley, 2000	Journal of Science and Medicine in Sport	Elite fencers are faster in reaction and total response time and more accurate than novices; target choice and lunge

Title	Author(s), Year	Journal	Key Findings
fencing: A comparison of elite and novice fencers			distance systematically affect timing and EMG patterning.
The ability to correct an on-going action: Accuracy and correction time in elite fencing	Zeuwts et al., 2017	Archives of Budo	Elite fencers can correct an on-going attack when the target changes; correction time and accuracy quantify on-line motor adjustment, demonstrating adaptive control.
Effect of uncertainty during the lunge in fencing	Gutiérrez-Dávila et al., 2014	Journal of Sports Science and Medicine	Uncertainty (higher error probability) lengthens the reaction response and alters centre-of-mass kinematics during the lunge.
Response timing in the lunge and target change in elite versus medium-level fencers	Gutiérrez-Dávila et al., 2013	European Journal of Sport Science	Elite and medium-level fencers differ in response-timing parameters and segmental kinetic sequencing during a lunge with target change.
Sensorimotor specificities in balance control of expert fencers and pistol shooters	Herpin et al., 2010	Journal of Electromyography and Kinesiology	Fencers develop sport-specific postural sensorimotor strategies; their balance control and neurosensory organisation differ from those of pistol shooters.
Movement organization and neuromuscular coordination underlying offensive performance in para-fencing	Mahdi et al., 2026	Frontiers in Sports and Active Living	Inertial-sensor kinematic profiles reveal distinct movement-organisation and neuromuscular-coordination strategies underlying para-fencing offensive performance, beyond execution speed alone.
On the Biomechanics of the Foil "Flick"-Kinematical Comparison of the Execution in Non-elite and Elite Fencers	Nikolov et al., 2024	International Journal of Human Movement and Sports Sciences	Kinematic comparison of the foil flick shows elite–non-elite differences in multi-joint (shoulder–elbow–wrist) coordination and blade control.
Comparing lunge techniques depending on the weapon used: Differences between foil and epee fencers	Dedieu et al., 2024	Journal of Physical Education and Sport	Despite differing priority rules, foil and épée fencers exhibit largely similar interlimb and intergirdle coordination patterns during the lunge.
The effect of nonleading foot placement on power and velocity in the fencing lunge	Gresham-Fiegel et al., 2013	Journal of Strength and Conditioning Research	The placement angle of the non-leading foot influences the power and velocity generated in the fencing lunge.
Somatic determinants of hit precision in female foil fencers	Krzykała et al., 2023	Archives of Budo	Somatic characteristics and morphological asymmetry are associated with hit precision in junior female foil fencers.
Assessing the validity of two-dimensional video analysis for measuring lower limb joint angles during fencing lunge	Chida et al., 2024	Frontiers in Sports and Active Living	Two-dimensional video analysis is a valid, low-cost alternative to three-dimensional motion capture for measuring lower-limb joint angles during the fencing lunge.

Table 4. Classification of included studies by population, design, theme, task, and primary outcome.

Author(s), Year	Population / Weapon	Design	Theme / Focus	Task / Condition	Primary Outcome
Guilhem et al., 2014	Sabre; elite female (n=10)	Quant. descriptive	Neuromuscular / EMG coordination	Maré-fente; isokinetic + EMG + force platform	Muscle coordination & mechanical effectiveness
Plantard et al., 2017	Lunge; modelling pilot	Quant. descriptive (pilot)	Motion adaptation	Motion capture / modelling	Adaptation of lunge motion
Akbaş et al., 2021	Elite (n=8) vs students (n=9)	Quant. non-randomised	Postural / feedforward control	Lunge; 3 stance widths; self-paced vs RT	Onset of postural adjustments
Akbaş et al., 2024	Elite female (n=8)	Quant. descriptive	Postural / feedforward control	Lunge; base-of-support widths	EPA & COM/wrist kinematics

Author(s), Year	Population / Weapon	Design	Theme / Focus	Task / Condition	Primary Outcome
Guan et al., 2018	Elite (n=7) vs intermediate (n=12)	Quant. non-randomised	Lunge kinematics & kinetics	Maximal lunge; GRF + 3D kinematics	Determinants of lunge speed
Frère et al., 2011	Expert (n=8)	Quant. descriptive	Neuromuscular / EMG coordination	Flèche; 3D motion + EMG wavelet	Kinematic/EMG classification
Balkó et al., 2018	Épée; elite vs beginner (n=28)	Quant. non-randomised	Neuromuscular / EMG coordination	Lunge to stimulus; sEMG	Muscle-activation timing
Borysiuk et al., 2022	Épée	Quant. descriptive	Response timing & adaptability	Straight lunge; EMG + GRF	Anticipatory indicators of effectiveness
Balkó et al., 2016	Different skill levels	Quant. non-randomised	Neuromuscular / EMG coordination	Lunge; EMG + reaction time	Coordination & reaction time
Williams & Walmsley, 2000	Elite vs novice	Quant. non-randomised	Response timing & adaptability	Lunge; target choice × distance; EMG	Response timing & accuracy
Zeuwts et al., 2017	Elite	Quant. descriptive	Response timing & adaptability	Attack with target change	On-line correction ability
Gutiérrez-Dávila et al., 2014	Regional-level (n=18)	Quant. descriptive	Response timing & adaptability	Lunge under uncertainty; force platform	Reaction response & COM
Gutiérrez-Dávila et al., 2013	Elite (n=13) vs medium (n=17), male	Quant. non-randomised	Response timing & adaptability	Lunge with target change; force platform	Response timing & kinetics
Herpin et al., 2010	Fencers vs pistol shooters	Quant. non-randomised	Postural / balance control	Posturography with sensory conflict	Balance & sensorimotor strategy
Mahdi et al., 2026	Para-fencers	Quant. descriptive	Para-fencing movement organisation	Offensive actions; IMU kinematics	Performance strategies / coordination
Nikolov et al., 2024	Foil; elite vs non-elite	Quant. descriptive	Lunge kinematics & kinetics	Flick; multi-joint kinematics	Multi-joint coordination
Dedieu et al., 2024	Foil (n=16) vs épée (n=16)	Quant. non-randomised	Neuromuscular / EMG coordination	Lunge; coordination analysis	Interlimb/intergirdle coordination
Gresham-Fiegel et al., 2013	Fencers (lunge)	Quant. non-randomised	Lunge kinematics & kinetics	Lunge; varied foot placement	Power & velocity
Krzykała et al., 2023	Foil; junior female (n=60)	Quant. descriptive	Somatic determinants	Anthropometry / body composition	Somatic determinants & asymmetry
Chida et al., 2024	Male fencers (n=22)	Quant. descriptive	Measurement validation	Lunge; 2D vs 3D analysis	Measurement validity

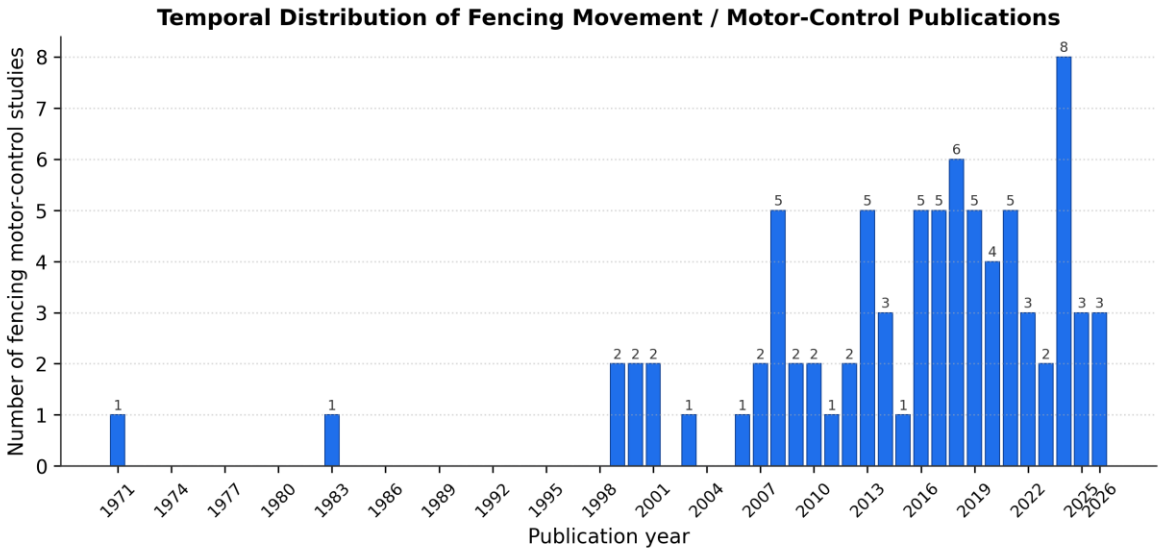

Figure 2. Temporal distribution of fencing movement and motor-control publications identified in the corpus, showing a marked increase over the past decade.

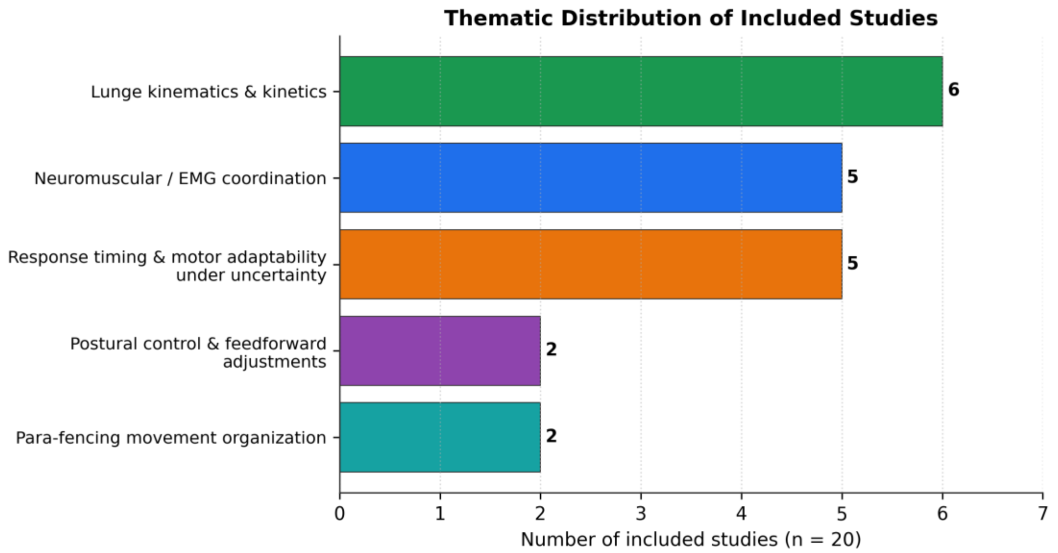

Figure 3. Thematic distribution of the 20 included studies across the principal movement and motor-control foci.

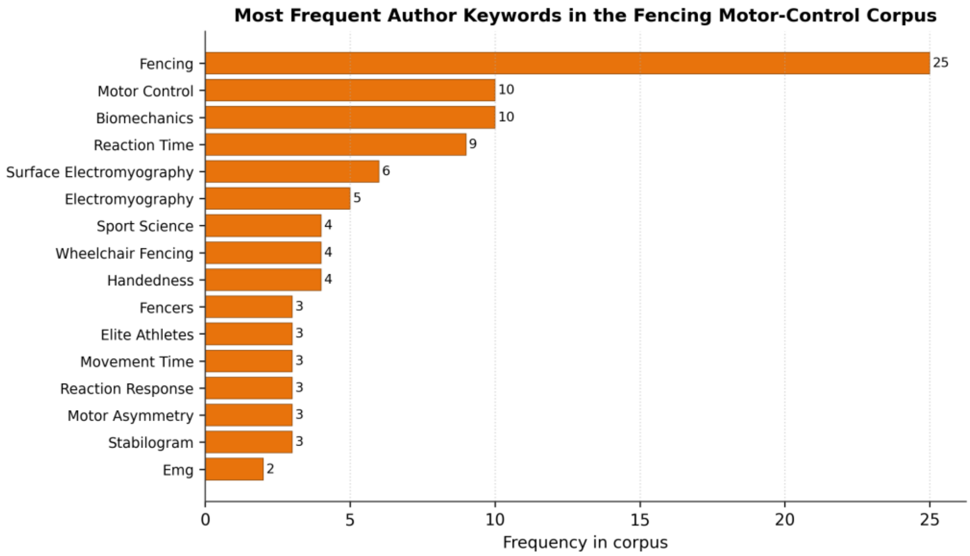

Figure 4. Most frequent author keywords in the fencing motor-control corpus, confirming the centrality of motor control, biomechanics, reaction time, and electromyography.

Thematic Synthesis

RQ1 – Neuromuscular coordination and movement organisation across skill levels

Across the 20 included studies, expertise was consistently associated with differences in movement organisation and timing rather than speed alone. Guilhem et al. (2014) linked lower-limb muscular coordination to the mechanical effectiveness of a sabre attack, while Frère et al. (2011) identified temporal EMG patterns that differentiated attack execution. Balkó et al. (2016, 2018) similarly reported skill-related differences in muscular activation and response timing, and Guan et al. (2018) showed greater rear-leg ground-reaction-force production and centre-of-gravity velocity in elite than intermediate fencers. These findings converge on a coordination-based interpretation of expertise, but the specific indicators vary across weapon, task, and measurement method.

Postural preparation provides a second convergent marker of expertise. Akbaş et al. (2021) reported earlier anticipatory and early postural adjustments in elite fencers, while Akbaş et al. (2024) demonstrated that base-of-support width changes early postural adjustments and centre-of-mass acceleration. Williams and Walmsley (2000) found faster and more accurate responses in elite fencers, but Gutiérrez-Dávila et al. (2013c) also illustrates an important nuance: elite and medium-level fencers did not differ on every reaction-time measure, even though their movement sequencing and performance variables differed. Training evidence further suggests that reaction and coordination capacities can be modified (Balkó et al., 2017; Di Cagno et al., 2020; Lopatenko et al., 2021). Collectively, these studies support an expertise-sensitive but task-dependent model of neuromuscular organisation.

RQ2 – Mechanisms of motor adaptability under uncertainty

The adaptability evidence indicates that fencing attacks are not fixed motor sequences. Zeuwts et al. (2017) demonstrated the ability of elite fencers to correct an ongoing attack after target displacement, while Gutiérrez-Dávila et al. (2013a, 2013c, 2014) showed that target change and uncertainty alter response timing and movement organisation. Plantard et al. (2017) provided an early modelling approach for describing motion adaptation, and Sorel et al. (2019) examined lunge accuracy and response time under uncertain conditions. Evidence from auditory and visual occlusion studies also indicates that skilled fencers use anticipatory information to recognise attacks (Allerdissen et al., 2017). These findings collectively support flexible perception-action coupling and online correction, although the evidence remains dominated by laboratory paradigms.

Postural and balance mechanisms appear central to this flexibility. Herpin et al. (2010) found fencing-specific sensorimotor strategies in balance control, and Akbaş et al. (2024) showed that stance width modifies postural preparation and centre-of-mass acceleration. Borysiuk et al. (2022) linked anticipatory EMG timing to ground-reaction-force development, supporting a feedforward component to attack preparation. Para-fencing studies (Borysiuk et al., 2020, 2022, 2023; Mahdi et al., 2026) further indicate that multiple movement solutions can support offensive performance. Thus, variability should be interpreted cautiously: the reviewed studies suggest functional flexibility, but the field lacks standardised metrics that distinguish beneficial variability from performance-degrading variability.

RQ3 – Technical and mechanical determinants of attack effectiveness

The evidence identifies several coach-manipulable factors associated with attack effectiveness. Gresham-Fiegel et al. (2013) showed that non-leading-foot placement affects lunge power and velocity, whereas Guan et al. (2018) identified rear-leg propulsion as an important speed determinant. Akbaş et al. (2021, 2024) demonstrated the relevance of feedforward postural timing and base-of-support configuration. Dedieu et al. (2024) reported broadly similar interlimb and intergirdle coordination between foil and épée fencers, suggesting that some coordination principles may transfer across weapons. However, these associations should not be interpreted as universal causal determinants because most evidence is cross-sectional and task-specific.

Weapon- and technique-specific studies add important qualifications. Nikolov et al. (2024) identified elite–non-elite differences in multi-joint coordination during the foil flick; Krzykała et al. (2023) related somatic characteristics and asymmetry to hit precision; and Chida et al. (2024) supported the validity of two-dimensional video analysis for lower-limb joint-angle measurement. Together with the work of Williams and Walmsley (2000), Gutiérrez-Dávila et al. (2013c), Zeuwts et al. (2017), and Akbaş et al. (2021, 2024), these studies suggest a practical framework centred on rear-leg propulsion, foot placement, base-of-support control, and preparatory timing, while recognising that their relative importance depends on weapon and task.

Comparative and Critical Analysis

Methodologically, the corpus is dominated by cross-sectional, descriptive, and non-randomised studies. Fifteen or more empirical studies across the corpus contribute directly to the coordination, timing, adaptability, and technique framework: Guilhem et al. (2014), Frère et al. (2011), Balkó et al. (2016, 2018), Guan et al. (2018), Akbaş et al. (2021, 2024), Williams and Walmsley (2000), Gutiérrez-Dávila et al. (2013a, 2013c, 2014), Zeuwts et al. (2017), Herpin et al. (2010), Borysiuk et al. (2022), Gresham-Fiegel et al. (2013), Dedieu et al. (2024), Nikolov et al. (2024), Krzykała et al. (2023), and Chida et al. (2024). Their findings broadly converge on expertise-related reorganisation of movement, but the heterogeneity of skill definitions, weapon type, sample composition, and task design prevents a single universal biomechanical profile. Sample sizes are also commonly small, reducing precision and limiting subgroup analyses.

Discussion

Interpreted collectively, the findings indicate that fencing attack performance reflects coordinated preparation, propulsion, postural control, and online correction. The findings bridge information-processing and dynamical/feedforward-control perspectives: shorter reaction times and improved accuracy indicate more efficient information processing, whereas target-change responses and functional variability indicate flexible adaptation. The evidence therefore supports a view of expertise as the efficient deployment of prepared but modifiable motor solutions rather than rigid automaticity.

Practically, coaches can emphasise rear-leg force production, consistent but task-appropriate foot placement, base-of-support management, and anticipatory postural timing. Representative practice conditions involving target uncertainty, feints, and changing spatial demands may be useful for developing online correction, consistent with the findings of Zeuwts et al. (2017), Gutiérrez-Dávila et al. (2013a, 2013c, 2014), and Sorel et al. (2019). Because Chida et al. (2024) supports two-dimensional video analysis for lower-limb joint-angle assessment, applied monitoring need not always require laboratory motion capture.

External validity, limitations, and methodological implications

Future longitudinal and intervention studies should predefine expertise-related outcomes, include repeated measures, and test whether changes in coordination precede changes in performance. Para-fencing and female fencers should be represented more consistently, and representative training tasks should complement laboratory measures to strengthen ecological validity.

Future primary studies should report weapon, sex, skill level, sample size, task constraints, target characteristics, sensor placement, signal-processing procedures, and outcome definitions in standardised formats. For biomechanics, reporting absolute values and normalised values together, clear event definitions for movement onset and foot-off, reliability information for measurement systems, and effect sizes with confidence intervals would improve comparability. For movement variability, studies should predefine the variability metric, its time scale, and its functional interpretation rather than treating variability as a single undifferentiated construct.

The review also has important methodological limitations. Only three databases were searched; the search date is not documented in the current manuscript; English-language and peer-reviewed studies were required; most included designs were cross-sectional; and the database export did not preserve author-affiliation information, preventing geographic analysis. The manuscript also does not contain a prospective protocol-registration record or a screening log from which Cohen's kappa can be independently reconstructed. These omissions should be resolved from the study archive where possible rather than inferred after the fact.

Cross-weapon generalisability remains incomplete. Dedieu et al. (2024) found substantial similarities between foil and épée lunge coordination, but weapon-specific studies such as Guilhem et al. (2014) and Nikolov et al. (2024) show that task and weapon demands can alter the relevant coordination features. Ecological validity is also a concern because many studies use controlled laboratory stimuli, fixed targets, or force-platform tasks that simplify competitive exchanges. Findings from laboratory tasks should therefore be translated cautiously to full bouts.

In direct answer to the research questions, neuromuscular coordination and movement organisation differ systematically with skill level, especially in preparatory timing, muscular sequencing, and rear-leg propulsion (RQ1); motor adaptability is supported by feedforward postural control, balance strategies, and the ability to correct ongoing actions under uncertainty (RQ2); and attack effectiveness is associated with rear-leg propulsion, foot placement, base-of-support configuration, and preparatory timing, although their relative contribution is task-dependent (RQ3).

Conclusions

This systematic review of 20 empirical studies indicates that successful fencing lunges and attacks depend on the organisation, timing, propulsion, postural control, and adaptability of whole-body movement rather than speed alone. Across the corpus, higher-skilled fencers generally showed earlier preparatory adjustments, distinct muscular sequencing, greater rear-leg propulsion, and stronger capacity for online correction. The evidence also suggests that movement variability can support adaptation, although the field currently lacks standardised measures for functional variability. The most consistently supported modifiable factors are rear-leg propulsion, non-leading-foot placement, base-of-support configuration, and feedforward postural timing. Interpretation should remain cautious because the evidence base is predominantly cross-sectional, sample sizes are often small, the search was limited to three databases, and key reproducibility information such as the exact search date and screening agreement is not documented in the current manuscript.

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