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Kinetic-chain and perception–action determinants of jump smash accuracy in badminton: a systematic review of strength, power and hand–eye coordination

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ABSTRACT

The jump smash is the most decisive attacking stroke in badminton, yet an integrated account of how arm muscle strength, leg explosive power and hand–eye coordination jointly shape its accuracy is lacking. This systematic review synthesised recent evidence on these determinants, examined their moderators and identified methodological gaps. Following PRISMA 2020, Scopus was searched for 2021–2026 publications; studies were eligible if they involved racket-sport players and related at least one physical or perceptual-motor determinant to a sport-specific performance outcome. Of 76 records identified, 53 full texts were assessed and 44 studies (32 in badminton, involving youth, recreational, university and elite players of both sexes) were included, appraised with the FICO quality framework and analysed through thematic synthesis (descriptive coding, descriptive themes and analytical themes). Upper-limb, particularly shoulder, strength was the most consistent correlate of smash velocity, explaining 57–64% of its variance in young players, and responded to plyometric and low-load occlusion training. Lower-limb power improved reliably with plyometric and neuromuscular training, but its transfer to accuracy was inferred rather than measured. Hand–eye coordination and visuomotor training were associated with the most direct gains in striking accuracy. Neuromuscular and mental fatigue, maturation and sex moderated these relationships. No included study measured all three determinants together with smash accuracy, and the evidence is largely correlational and fragmented. It is therefore consistent with, but does not yet confirm, an integrated kinetic-chain and perception–action model in which strength and power may set the velocity ceiling while visuomotor control appears to govern accurate delivery. This framework is a theoretical synthesis that awaits validation in trials measuring all three determinants and smash accuracy together.



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Introduction

Badminton is one of the most widely played and fastest racket sports, with smash shuttlecock speeds exceeding those of any other racket-sport projectile and rallies that demand repeated explosive actions within seconds (Phomsoupha & Laffaye, 2015). Contemporary profiles describe it as an intermittent, high-intensity sport in which physical, technical, tactical and psychological qualities interact continuously (Phomsoupha & Laffaye, 2015; Ye et al., 2024), and recent syntheses of racket sports emphasise that performance cannot be reduced to a single capacity (Guarnieri et al., 2026; Yu et al., 2026). The smash occupies a privileged position because it is

the stroke most frequently associated with winning points at advanced levels, so its determinants translate most directly into competitive outcomes.

The jump smash is a complex open-skill action in which the player must time a vertical take-off, generate force through the lower limbs, transfer it through the trunk, accelerate the racket arm and contact a fast-moving shuttlecock at the highest possible point, while directing the shot to a narrow target zone. Speed alone is not sufficient: a fast smash that lands out, into the net or within the opponent's reach is tactically ineffective. Accuracy is therefore the criterion that integrates force production with control. Biomechanical modelling suggests that racket path geometry constrains smash time (Putra et al., 2024), and kinematic analyses show that lower-limb coordination during the forehand smash is sensitive to fatigue (Z. Zhou et al., 2025). Yet direct measurement of smash accuracy remains scarce: among the 44 studies identified in this review, only six primary studies quantified smash or hitting accuracy, using target-zone scores after triceps fatigue (Alkhawaldeh, 2022), hitting depth and accuracy after functional training (Chen, 2023), landing-point stability after core training (H. Zhou, 2024), target accuracy after the Shuttle Time programme (Niyazov et al., 2024), smash accuracy after caffeine ingestion (Feng et al., 2025) and smash-test strike accuracy after blood-flow-restriction training (Verma et al., 2026). Each examined a single determinant or acute condition, mostly in small samples, and none measured strength, power and coordination together with accuracy.

A substantial literature has examined physical determinants. Resistance, plyometric and core-strength programmes improve power, speed, agility and balance in badminton players (Deng et al., 2024; Ma et al., 2024; T. Wang et al., 2025); upper-extremity strength has been linked to shuttlecock velocity (Aydin et al., 2026); and sex- and side-specific shoulder strength profiles have been described in elite players (Nageswari et al., 2026). Studies in padel and tennis report associations between upper-body strength, jump capacity and stroke outputs (Ke, 2023; Sánchez-Alcaraz et al., 2025). A separate literature has identified spatial orientation, movement frequency and kinaesthetic differentiation as determinants of skill level in elite players (Jaworski et al., 2021) and associated eye–hand coordination with serving accuracy and shot precision (Ochor & Amasiatu, 2025). In table tennis, reactive agility depends more on visual reaction than on explosive strength (Horníková, 2022). These two literatures have developed largely in isolation, so the field lacks a common account of how these qualities combine within a single stroke.

Methodological advances now make an integrated analysis more feasible. Wearable electromyography and electrical muscle stimulation have been used to quantify lower-limb activation during the jump smash (Lin et al., 2025); functional principal component analysis has captured lower-limb coordination synergies (Z. Zhou et al., 2025); mixed-reality instruction and eye-tracking have been used to train visual attention (T.-C. Wang et al., 2026); and sensor-assisted tests provide valid alternatives to traditional hand–eye coordination assessments (Irawan et al., 2025). Stroboscopic and add-on visuomotor paradigms (Chang et al., 2022; Ren et al., 2025) and blood-flow-restriction training (Verma et al., 2026) have also been tested. These tools have not yet been synthesised around the jump smash.

Two gaps motivate this review. First, most physical-training studies report jump height, sprint time, agility or throw distance as proxies, few report smash velocity and fewer still report accuracy (Deng et al., 2024; Panda et al., 2022; T. Wang et al., 2025), whereas coordination studies commonly assess serves or clears rather than the jump smash (Chaeroni et al., 2023; Suh & Jeong, 2025). The contribution of each determinant to jump smash accuracy has therefore been inferred rather than demonstrated. Second, kinetic-chain reasoning and perception–action approaches are rarely combined (Horníková, 2022; Zhang et al., 2024), and moderators are inconsistently considered: maturation alters training responsiveness (Shi et al., 2026; Weng et al., 2025), age and sex shape smash metrics (Pambudi et al., 2025), and neuromuscular and mental fatigue degrade stroke velocity, accuracy and psychomotor speed (Alkhawaldeh, 2022; C. Ding et al., 2024; Habay et al., 2021). Most primary studies are small and short, and adjacent reviews rate the certainty of evidence as low (Deng et al., 2024; Ma et al., 2024). No prior review has treated the jump smash as an integrated outcome combining velocity and accuracy, or considered psychological states such as anxiety and mental fatigue alongside physical determinants (da Costa et al., 2022; Feng et al., 2025). Existing reviews have addressed fitness outcomes of single modalities, namely plyometric (Deng et al., 2024), core (Ma et al., 2024; Yu et al., 2026) and resistance training (T. Wang et al., 2025), stroboscopic vision training (Ren et al., 2025) and mental fatigue (C. Ding et al., 2024), and the most smash-specific of them concluded that evidence on smash velocity and accuracy was limited (T. Wang et al., 2025). The present review extends this work by making accuracy, rather than fitness, the organising outcome and by integrating physical and perceptual-motor determinants within one framework.

This review therefore treats jump smash accuracy as a composite outcome produced by a force-generating kinetic chain and a perception–action control system, synthesising the 2021–2026 Scopus literature through this dual lens to propose an integrated training framework and research agenda. As a secondary, non-experimental design, a systematic review does not require an a priori sample-size calculation; its adequacy depends instead

on comprehensive retrieval, explicit eligibility criteria and quality appraisal, which are reported in the Method. Jump smash accuracy was operationally defined as the spatial precision of the smash relative to a predefined target, expressed as target-zone scores, success rates, landing-point deviation or validated strike-accuracy test scores as reported in the primary studies, whereas smash velocity was defined as shuttlecock or racket speed measured by radar or motion analysis. Three research questions guided the review:

RQ1: What is the evidence on the influence of arm muscle strength and leg explosive power on jump smash velocity and accuracy in badminton and related racket sports?

RQ2: How do hand–eye coordination and visuomotor control contribute to smash and stroke accuracy, and can they be improved through targeted training?

RQ3: How do strength, power and coordination interact with each other and with physiological, psychological and developmental moderators to determine smash performance, and what are the implications for training design?

Method

A systematic literature review design was adopted because the research questions require a transparent, reproducible appraisal of a fragmented evidence base; specifying search, eligibility and appraisal procedures in advance reduces selection bias (Tranfield et al., 2003). Reporting followed the PRISMA 2020 statement and its 27-item checklist and flow diagram, which update the original PRISMA guidance (Liberati et al., 2009; Page et al., 2021). Because the included studies were heterogeneous in design, population, intervention and outcome, meta-analysis was not appropriate; evidence was integrated through thematic synthesis supported by descriptive bibliometric analysis. Heterogeneity was assessed at the clinical and methodological level by tabulating the population, design, exposure and outcome of each study (Table 2): the 44 studies comprised 24 experimental, 12 observational or modelling and 8 review designs, spanned youth to elite players in four racket sports, and used non-comparable instruments (radar velocity, target-zone accuracy, wall-toss coordination, sensor-based tests and kinematic indices) and effect metrics (standardised mean differences, correlation coefficients and explained variance). Because too few primary studies shared the same design, determinant and comparable outcome metric, statistical pooling and I^2 estimation would have been uninformative, so a narrative thematic synthesis was chosen.

Scopus was selected as the single information source because of its broad coverage of peer-reviewed sport science, biomechanics, physiology and physical education journals and its complete exportable metadata. A single database was used deliberately: Scopus indexes the major sport-science and biomechanics journals also covered by Web of Science, includes the journals indexed in MEDLINE/PubMed, and provides uniform metadata required for the bibliometric analysis; merging differently structured exports would have introduced inconsistencies in the country and keyword counts. The resulting risk of retrieval bias is acknowledged as a limitation. The search, executed and exported on 19 October 2026, combined three concept blocks (racket-sport population terms; physical and perceptual-motor determinant terms; stroke and performance outcome terms) with OR within and AND between blocks, using truncation and the TITLE-ABS-KEY field code. The population block deliberately included other racket sports so that transferable evidence on overhead striking could be considered, while badminton-specific findings were prioritised in interpretation. Non-badminton studies were treated as transferable evidence only if they (a) involved an overhead or forceful striking action, or a perceptual-motor task requiring interception of a fast-moving object, and (b) reported a determinant listed in Table 1 together with a stroke-related or sport-specific performance outcome; twelve studies (tennis, table tennis, padel or multi-sport) met these conditions and were used to corroborate, not replace, badminton evidence. The string was:

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TITLE-ABS-KEY ( badminton OR "racket sport*" OR "racquet sport*" OR tennis OR "table tennis" OR padel OR squash ) AND TITLE-ABS-KEY ( strength OR power OR plyometric* OR "neuromuscular" OR "hand-eye coordination" OR "eye-hand coordination" OR coordination OR visuomotor ) AND TITLE-ABS-KEY ( smash OR accuracy OR "stroke performance" OR "skill" OR performance ) AND PUBYEAR > 2020
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The CSV export (33 metadata fields) constituted the authoritative evidence base for all counts, tables and figures; methodological and seminal sources were cited only to support methods and background. Eligibility criteria are summarised in Table 1. Studies were eligible if they involved racket-sport players and examined at least one physical, perceptual-motor or moderating factor in relation to a sport-specific performance outcome. All primary designs (randomised and non-randomised trials, crossover, cross-sectional, correlational, validity and modelling studies) and systematic or narrative reviews were eligible; no minimum sample size was imposed, but sample size was considered in the FICO Information score.

Table 1. Inclusion and exclusion criteria

Criterion	Inclusion	Exclusion
Language	English only	Non-English (e.g., Russian, Korean, Ukrainian)
Document type	Peer-reviewed article or review (final or in-press)	Conference paper, conference review, note, editorial, retracted article
Publication period	2021–2026 (search date 19 October 2026)	Before 2021
Population	Racket-sport players of any age, sex or level (badminton prioritised; tennis, table tennis, padel)	Clinical or patient populations; non-racket sports only; non-athletes without a sport-skill outcome
Exposure / determinant	Upper-limb strength/power, lower-limb power, core/neuromuscular capacity, hand–eye coordination, visuomotor or perceptual skill, or a moderator (fatigue, maturation, sex, psychological state)	Nutrition, pharmacology or injury outcomes without a performance determinant
Outcome	Smash velocity or accuracy, stroke/hitting accuracy, sport-specific skill or physical performance relevant to the smash	No sport-specific performance outcome
Subject area	Sport science, biomechanics, physiology, motor control, physical education	Unrelated disciplines (e.g., surgery, robotics without athletes)
Accessibility	Full text retrievable with a DOI	Abstract only / not retrievable
Relevance	Directly addresses determinants of racket-sport stroke performance	Tangential mention only

Selection proceeded in three stages: filtering by document type, publication status and language using the metadata; title and abstract screening; and full-text assessment. Two reviewers screened independently, with disagreements resolved by discussion or a third reviewer. Inter-rater agreement was quantified with Cohen's kappa for title–abstract screening (κ = [authors to insert]) and full-text eligibility (κ = [authors to insert]). Full-text exclusions were recorded as out of scope, wrong method or no performance outcome, or inaccessible full text. Methodological quality was appraised with the FICO framework: Focus (clarity of the question and its relevance to stroke determinants), Information (adequacy of design, sample, measurement and statistics), Context (description of population, level, sex, age or maturity and setting) and Outcome (use of sport-specific outcomes, ideally smash velocity or accuracy). Each dimension was scored 0–2 (total 0–8); scores of 7–8 were classified as high, 5–6 as moderate and 4 as low-moderate quality. FICO was preferred to design-specific tools such as the JBI checklists or CASP because it allows one scale to be applied consistently across the experimental, observational, modelling and review designs included. Scores were used to weight interpretation rather than to exclude studies, because excluding lower-quality but relevant studies would remove much of the available smash-specific information.

A standardised form recorded author(s), year, country, sport and population, design, sample, intervention or exposure, outcomes and key findings; details not reported were recorded as not available rather than inferred. Descriptive bibliometric analysis characterised studies by year, design and country (full counting of affiliations). Keyword co-occurrence was analysed on harmonised author and index keywords occurring in at least three studies, with clusters identified by modularity-based community detection following VOSviewer logic (van Eck & Waltman, 2010). Thematic synthesis proceeded in three stages (Thomas & Harden, 2008): line-by-line descriptive coding of findings; grouping codes into six descriptive themes (upper-limb strength and power; lower-limb power and jump; core and integrated neuromuscular training; hand–eye and visuomotor control; moderators; and multidimensional profiles); and generating analytical themes against the research questions, validated against the keyword clusters and checked for disconfirming evidence. This approach corresponds to the thematic synthesis framework rather than meta-ethnography or framework synthesis, because the included studies were predominantly quantitative and the aim was to aggregate and interpret findings rather than to reinterpret qualitative concepts.

Results and Discussions

The Scopus search returned 76 records, with no duplicates because all originated from a single export. Before screening, nine records were removed: five ineligible document types (one note, one conference review, two conference papers and one editorial), two retracted articles and two non-English articles. Of 67 records screened,

12 were excluded as off-topic. Fifty-five reports were sought, two could not be retrieved, and 53 full texts were assessed; nine were excluded as out of scope (n = 6) or for an ineligible method or no performance outcome (n = 3). Forty-four studies were included (Figure 1).

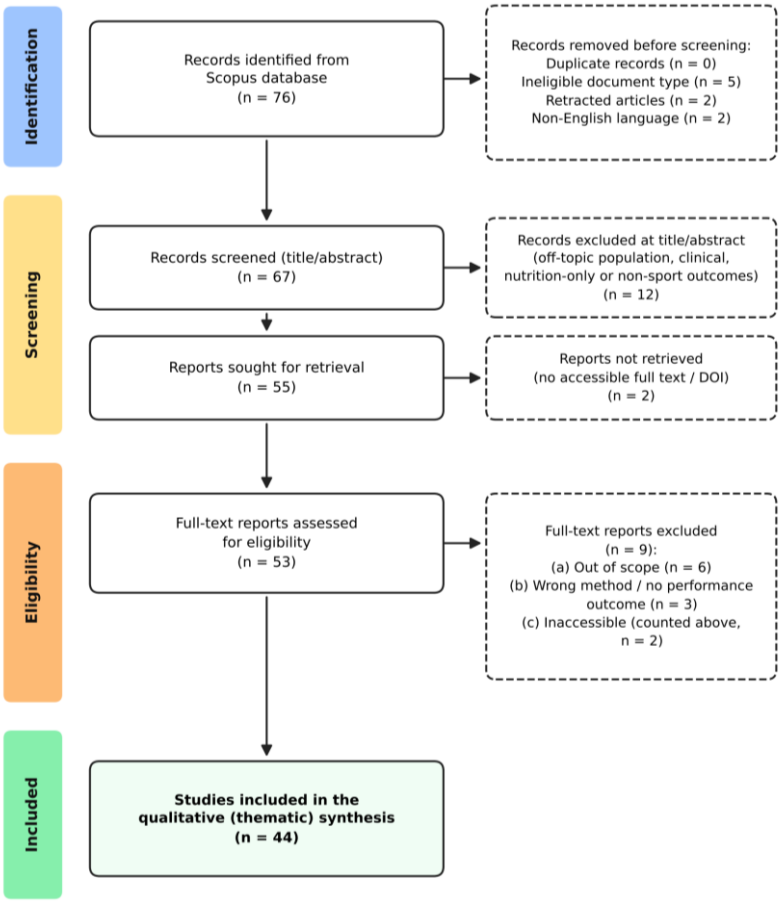


Figure 1. PRISMA 2020 flow diagram of study identification, screening and inclusion

The included studies were published between 2021 and 2026, with clear acceleration after 2023: three in 2021, six in 2022, four in 2023, eleven in 2024, thirteen in 2025 and seven in the partial year 2026 (Figure 2). The distribution across the five complete years (2021–2025) departed significantly from uniformity ($\chi^2(4) = 10.43$, $p = .034$), and the annual rate rose from 4.3 studies per year in 2021–2023 to 12.0 in 2024–2025 ($\chi^2(1) = 9.53$, $p = .002$, expected counts weighted by number of years). Twenty-four (54.5%) used experimental or intervention designs, twelve (27.3%) were observational, correlational or modelling studies and eight (18.2%) were reviews. Badminton was the focal sport in 32 studies; the remainder examined tennis, table tennis, padel or mixed samples.

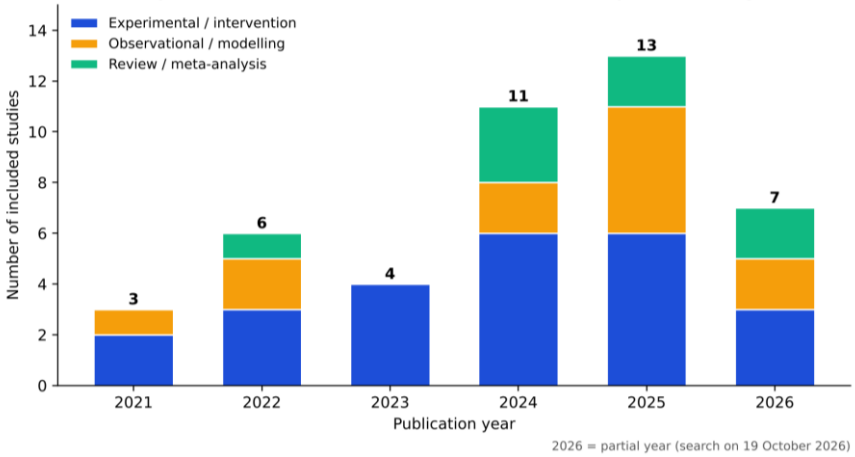


Figure 2. Annual distribution of the 44 included studies by research design (2026 is a partial year)

Output was geographically concentrated (Figure 3). China contributed to 17 studies, followed by Indonesia and Malaysia (five each), India (four), Taiwan and Spain (three each) and Turkey (two); Malaysia's contribution was driven largely by Chinese–Malaysian review collaborations. European, African and American contributions were sparse, indicating limited ethnic, cultural and competitive-system diversity. The distribution across the seven leading countries was significantly uneven ($\chi^2(6) = 28.67$, $p < .001$): China alone accounted for 38.6% (17/44) of the studies, and 34 studies (77.3%) included at least one author affiliation in Asia. This concentration matters for knowledge validity, because training cultures, competitive structures and athlete anthropometry differ across regions, so findings derived largely from Asian samples may not generalise to European, African or American players.

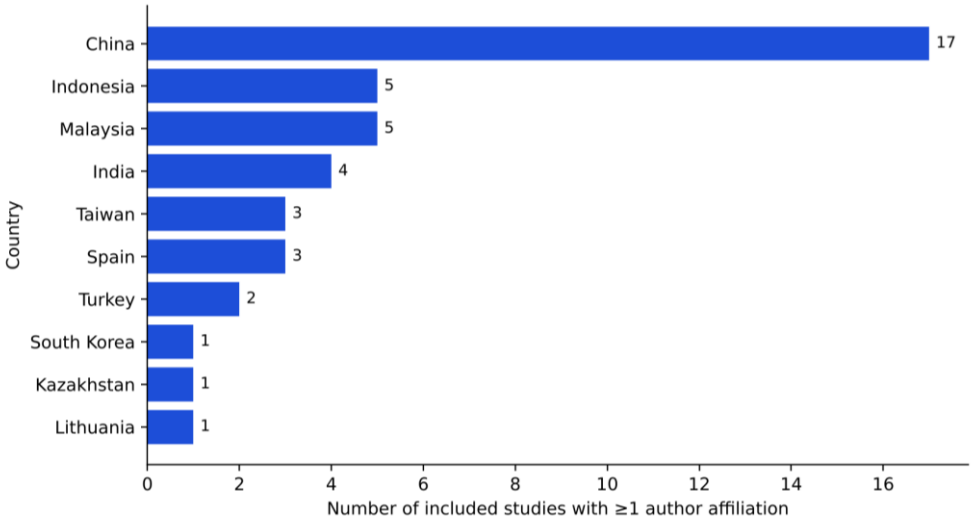


Figure 3. Top 10 contributing countries among included studies (full counting of author affiliations)

The keyword network (Figure 4) revealed two main clusters. The first, centred on badminton, muscle strength, resistance and plyometric training, power, agility and smash, represents the physical-conditioning stream; the second, centred on racket sports, motor performance, reaction time, coordination, accuracy and velocity, represents the perceptual-motor stream. Sparse links between smash and accuracy, and between hand–eye coordination and strength, illustrate the separation of the two literatures that motivated this review. Table 2 classifies all included studies by design, theme and quality, with the ten studies most directly relevant to the jump smash marked.

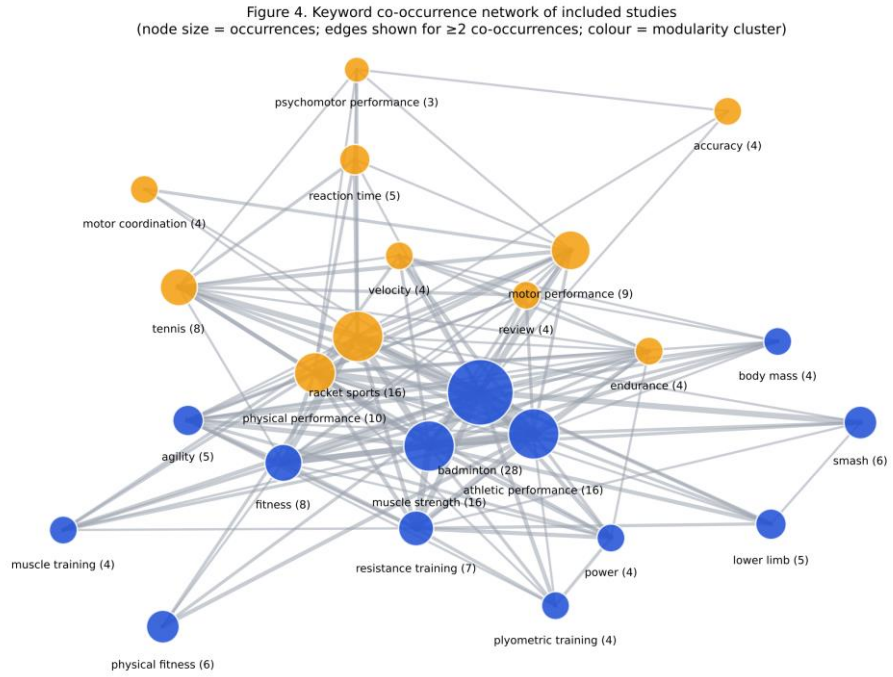


Figure 4. Keyword co-occurrence network of included studies (keywords occurring in ≥3 studies)

Table 2. Classification of the 44 included studies by design, theme and FICO quality score

Author(s) (year)	Country	Design	Sport / sample	Theme	Key outcome	FICO
Yu et al. (2026)	China, Malaysia	SR & MA	Racket sports	Core/NM	Improved strength, balance, ball velocity and shot accuracy	8 (H)
Sm et al. (2025)	India	RCT	Badminton	Core/NM	Improved dynamic balance, flexibility and footwork	5 (M)
H. Zhou (2024)	China	RCT	Badminton	Core/NM	Higher batting speed and landing-point stability	6 (M)
Ma et al. (2024)	Malaysia, China	SR & MA	Badminton	Core/NM	Improved power and front/back-court skills	8 (H)
Chen (2023)	China	Controlled exp.	Badminton (youth)	Core/NM	Improved baseline hitting depth and accuracy	6 (M)
Zhao et al. (2021)	China	Experimental	Badminton (female)	Core/NM	Improved FMS, asymmetry, fitness and special abilities	6 (M)
T.-C. Wang et al. (2026)	Taiwan	RCT	Badminton	HEC/VM	More successful shots; higher fixation count and saccade velocity	7 (H)
Suh & Jeong (2025)	South Korea	Experimental	Badminton	HEC/VM	Quantitative feedback improved retention accuracy and wrist kinematics	7 (H)
Ochor & Amasiatu (2025)*	Nigeria	Cross-sectional	Badminton (students)	HEC/VM	Eye–hand coordination linked to serve accuracy and shot precision	6 (M)
Irawan et al. (2025)	Indonesia	Validity study	Multi-sport	HEC/VM	High agreement of sensor and traditional hand–eye tests	5 (M)
Ren et al. (2025)	China	SR	Multi-sport	HEC/VM	Better visual processing, hand–eye precision and reaction	6 (M)
Zhang et al. (2024)	USA	Field exp.	Badminton	HEC/VM	Experienced players used action-scaled affordances more accurately	6 (M)
Chaeroni et al. (2023)*	Indonesia	Quasi-exp. 2×2	Badminton	HEC/VM	Media effect depended on coordination level (serve, clear, smash)	6 (M)
Horníková (2022)	Slovakia	Correlational	Table tennis	HEC/VM	Reactive agility driven by visual reaction more than jump power	5 (M)
Chang et al. (2022)	Taiwan	Controlled trial	Tennis	HEC/VM	Faster eye–hand RT, agility and strokes; gains lost after cessation	6 (M)
Jaworski et al. (2021)*	Poland	Correlational	Badminton (elite)	HEC/VM	Spatial orientation, movement frequency, kinaesthetic differentiation explain skill	7 (H)
Niyazov et al. (2024)*	Kazakhstan, Lithuania	RCT	Badminton	Integrated	Improved speed and smash/short-shot target accuracy	7 (H)
Lin et al. (2025)*	China	Crossover	Badminton	LL power	Better jump-smash and squat-jump output; higher rectus femoris activation	7 (H)
Weng et al. (2025)	Taiwan	Experimental	Badminton (youth)	LL power	Post-PHV gains in sprint, CMJ, agility; pre-PHV in balance	6 (M)
Z. Zhou et al. (2025)*	China, Canada	Pre–post, FPCA	Badminton	LL power	Fatigue increased lower-limb coordination complexity in the smash	6 (M)
Martín-Miguel et al. (2025)	Spain	Cross-sectional	Multi-sport	LL power	Discipline-specific lower-limb strength reference values	6 (M)
Liu (2024)	China	Pre–post	Badminton	LL power	Larger joint ROM, faster decisions, better rally shot output	5 (M)
Li & Li (2024)	China	Controlled exp.	Badminton	LL power	Improved lower-limb strength and anaerobic capacity	4 (L-M)

Author(s) (year)	Country	Design	Sport / sample	Theme	Key outcome	FICO
Deng et al. (2024)	Malaysia, China	SR & MA	Badminton	LL power	Improved power, agility, speed, balance; not reaction time	8 (H)
W. Ding & Wang (2023)	China	RCT	Badminton	LL power	Faster T-run, hexagon and 5-10-5 times	5 (M)
Panda et al. (2022)	India	RCT	Badminton	LL power	Jump improved in both arms; sprint only with plyometrics	6 (M)
Pambudi et al. (2025)	Indonesia, Turkey, Romania	Cross-sectional	Badminton (youth)	Moderator	Age and sex effects on smash, footwork and errors	6 (M)
Feng et al. (2025)	China	Crossover RCT	Badminton (elite)	Moderator	Caffeine improved anticipation and agility; smash accuracy unchanged	7 (H)
C. Ding et al. (2024)	Malaysia, China	SR	Racket sports	Moderator	Mental fatigue impaired stroke speed/accuracy and psychomotor response	7 (H)
Wismanadi et al. (2024)	Indonesia	RCT	Badminton (non-elite)	Moderator	Faster 48-h recovery of arm power, leg power and smash velocity	7 (H)
da Costa et al. (2022)	Brazil, UK	Narrative review	Ball sports	Moderator	Mental fatigue impaired perceptual, technical and tactical performance	5 (M)
Habay et al. (2021)	Belgium, Spain	Crossover	Table tennis	Moderator	Slower visuomotor reaction; altered EEG spectral power	6 (M)
Guarnieri et al. (2026)	Italy	SR	Table tennis	Profiles	Higher-level players faster in reaction and change of direction	6 (M)
Ye et al. (2024)	China	Delphi–AHP	Badminton (elite)	Profiles	Specialised agility, strength and endurance weighted highest	7 (H)
Putra et al. (2024)	Indonesia	Modelling	Badminton	Profiles	Cycloid racket path minimises smash time	5 (M)
X. Zhou et al. (2022)	Japan	Cross-sectional	Badminton (national)	Profiles	Shoulder pain linked to reduced trunk rotation and balance	6 (M)
T. Wang et al. (2025)	Malaysia	SR (PRISMA)	Badminton	UL/LL strength	Gains in power, speed, agility; limited smash velocity/accuracy evidence	8 (H)
Shi et al. (2026)*	China	RCT	Badminton (youth)	UL strength	Higher smash speed; maturation moderated adaptations	8 (H)
Nageswari et al. (2026)	India	Cross-sectional	Badminton (elite)	UL strength	Sex differences and dominant-side shoulder asymmetry	6 (M)
Verma et al. (2026)*	India	Quasi-exp.	Badminton (recreational)	UL strength	Greater handgrip strength and smash-test strike accuracy	7 (H)
Aydin et al. (2026)*	Turkey, Portugal	Cross-sectional	Badminton (U11)	UL strength	Shoulder strength predicted 57–64% of smash velocity	8 (H)
Sánchez-Alcaraz et al. (2025)	Spain	Cross-sectional	Padel (youth)	UL strength	Strength, CMJ and throws inter-related; sex differences	6 (M)
Ke (2023)	China	Controlled exp.	Tennis	UL strength	Higher wrist stability and stroke scores	5 (M)
Alkhawaldeh (2022)*	Jordan	Pre–post (fatigue)	Badminton (international)	UL strength	Fatigue impaired elbow motion, smash velocity and accuracy	8 (H)

Note. * = ten studies most directly relevant to the jump smash. FICO = Focus, Information, Context, Outcome (each 0–2; total 0–8); H = high (7–8), M = moderate (5–6), L-M = low-moderate (4). SR = systematic review; MA = meta-analysis; RCT = randomised controlled trial; NM = neuromuscular; HEC/VM = hand–eye coordination/visuomotor control; LL = lower-limb; UL = upper-limb; FPCA = functional principal component analysis; PHV = peak height velocity; CMJ = countermovement jump; AHP = analytic hierarchy process.

Regarding RQ1, upper-limb strength emerged as the most consistent physical correlate of smash velocity. In young competitive players, smash shuttlecock velocity correlated with all segmental upper-extremity strength variables, but after adjusting for sex and limb length only shoulder flexion, extension, internal and external rotation strength remained independent predictors, explaining approximately 57–64% of the adjusted variance

(Aydin et al., 2026). This is consistent with padel data showing inter-correlated upper-body throws, grip strength and jump capacity that differed by sex (Sánchez-Alcaraz et al., 2025), and with tennis data in which wrist strength training increased stroke stability (Ke, 2023). The shoulder thus appears to be the principal site of force transfer to the racket, with wrist and grip strength contributing to control at impact, and these capacities vary systematically by sex and side (Nageswari et al., 2026).

Upper-limb force capacities, and with them smash outputs, are trainable. A six-week randomised trial in youth players showed that both generic and technical upper-limb plyometrics improved overhead throw and smash speed more than regular training, with maturation moderating responsiveness (Shi et al., 2026). Blood-flow-restriction training with low loads produced greater gains in handgrip strength and smash-test strike accuracy than low-load training alone (Verma et al., 2026). Reviews reported improvements in power, ball velocity and shot accuracy after resistance and core training (T. Wang et al., 2025; Yu et al., 2026), although evidence on smash velocity and accuracy in badminton remained limited (T. Wang et al., 2025). Arm strength therefore appears to contribute to accuracy chiefly by increasing the force reserve available at a given speed, allowing the player to control the racket face rather than operate at maximal effort. Fatigue evidence reinforces this interpretation: triceps fatigue in international-level players degraded elbow kinematics and reduced both smash velocity and accuracy (Alkhawaldeh, 2022), and glutamine accelerated the joint recovery of arm power, leg power and smash velocity at 48 hours (Wismanadi et al., 2024). By contrast, caffeine improved anticipation and agility after fatigue but did not change smash accuracy (Feng et al., 2025), implying that accuracy depends on more than physical readiness.

Lower-limb explosive power is well supported as a trainable capacity but weakly linked to accuracy. Meta-analytic evidence shows small-to-moderate plyometric effects on power, agility, speed and balance, but not reaction time, with low certainty (Deng et al., 2024). Trials report improved jumping after plyometric and electromyostimulation training (Panda et al., 2022), faster change of direction after compound stretch-shortening training (W. Ding & Wang, 2023), greater lower-limb strength after jump-rope training (Li & Li, 2024) and maturity-dependent gains in sprint and countermovement jump after neuromuscular training (Weng et al., 2025). Only one study measured the jump smash directly, reporting that electrical stimulation combined with strength training enhanced jump smash and squat-jump performance and rectus femoris activation (Lin et al., 2025). Variable-speed running improved lower-limb mechanics and rally shot output (Liu, 2024), and lower-limb isometric reference values have been profiled across sports (Martín-Miguel et al., 2025).

The pathway from leg power to accuracy therefore remains largely inferential. Fatigue increases the number of coordination synergies needed to control the lower limbs during the smash, suggesting instability at take-off and landing (Z. Zhou et al., 2025). Core training adds an important link: it improved smash batting speed and landing-point stability (H. Zhou, 2024), hitting depth and accuracy (Chen, 2023), front- and back-court skills (Ma et al., 2024) and dynamic balance and footwork (Sm et al., 2025), while integrative neuromuscular training improved movement quality and special abilities in female players (Zhao et al., 2021). These findings support a kinetic-chain interpretation in which leg power raises the contact point and adds racket speed, while trunk stability determines whether that energy is transferred efficiently and accurately. Across RQ1, evidence strength decreases from strength–velocity relationships measured directly (Aydin et al., 2026; Shi et al., 2026), through lower-limb power supported mainly by proxies, to accuracy, measured in only a handful of physical-training studies (Alkhawaldeh, 2022; Chen, 2023; Verma et al., 2026). Effects were larger in youth and recreational than elite players, and no study isolated arm strength and leg power within one design. Upper-limb strength is thus a necessary but not sufficient condition for accurate smashing, and leg power contributes indirectly.

Regarding RQ2, hand–eye coordination showed the most direct relationship with stroke accuracy. Among 105 university students, higher wall-toss coordination scores accompanied better serving accuracy, reaction time and shot precision (Ochor & Amasiatu, 2025). Among elite Polish players, spatial orientation, movement frequency and kinaesthetic differentiation explained most of the variance in skill level, spatial orientation alone contributing about 42% (Jaworski et al., 2021). In table tennis, reactive agility was determined by visual reaction time more than by jump power, explosive strength being supportive rather than primary (Horníková, 2022). The perceptual component of coordination, the speed and precision of visual information processing, therefore appears to be a primary constraint on accurate striking.

Visuomotor control and stroke accuracy can be improved through targeted methods. Quantitative visual feedback produced superior retention of striking accuracy, inter-joint coordination and wrist kinematics in novices (Suh & Jeong, 2025). Eight weeks of mixed-reality instruction increased successful shots and improved fixation count and saccade velocity relative to coach-led teaching (T.-C. Wang et al., 2026). Add-on visuomotor training improved eye–hand response time, agility and stroke performance in tennis players, although gains disappeared three months after training stopped (Chang et al., 2022), and stroboscopic training enhances visual processing speed and hand–eye precision (Ren et al., 2025). Benefits were not uniform: audiovisual media helped

players with high coordination but were less effective for those with low coordination (Chaeroni et al., 2023). Experienced doubles players judged out-of-bounds flick serves more accurately using body- and action-scaled affordances (Zhang et al., 2024), and the Shuttle Time programme, combining coordination, reaction and technical-tactical exercises, improved smash and short-shot target accuracy (Niyazov et al., 2024). Measurement is progressing (Irawan et al., 2025), but no study assessed hand–eye coordination and jump smash accuracy together. Because most outcomes were serves, clears or ground strokes, the potentially greater role of coordination in the airborne jump smash remains untested.

Regarding RQ3, the three determinants appear to operate in sequence and in interaction rather than additively. Expert-weighted fitness models for elite singles players assign the highest weights to specialised agility, strength and endurance (Ye et al., 2024), table tennis profiles show that higher-level players have faster reaction and change of direction (Guarnieri et al., 2026), and modelling indicates that a cycloid-like racket path minimises smash time (Putra et al., 2024), implying that force must be applied along a coordinated trajectory. Strength and power set the velocity ceiling, the trunk transfers energy, and visuomotor control determines how much velocity reaches the target. Fatigue is the moderator with the most consistent evidence. Mental fatigue impaired stroke speed and accuracy and psychomotor response across racket sports through attentional mechanisms (C. Ding et al., 2024), slowed visuomotor reaction with altered EEG spectral power (Habay et al., 2021) and degraded perceptual, technical and tactical performance in ball sports (da Costa et al., 2022). The coordination component of accuracy is thus particularly vulnerable to cognitive load, which may explain why caffeine improved anticipation without changing smash accuracy (Feng et al., 2025).

Development, sex and injury status further condition how determinants are expressed. Post-peak-height-velocity players gained more in sprint, jump and agility and pre-peak players more in balance (Weng et al., 2025); age and sex influenced smash, footwork and error metrics (Pambudi et al., 2025); and shoulder pain in national-level players was associated with reduced trunk rotation and balance (X. Zhou et al., 2022), pointing to the kinetic chain as both a performance and a health pathway. The relative importance of each determinant also shifts along the athlete pathway: coordination and technique limit novices most (Suh & Jeong, 2025; T.-C. Wang et al., 2026), strength and power training yield measurable speed gains in trained youth (Shi et al., 2026), and fine perceptual differences distinguish elite players (Jaworski et al., 2021; Zhang et al., 2024). No single determinant is universally dominant; training emphasis should match the athlete's current limiting factor.

Methodologically, the field is dominated by short, small-sample trials, mostly four to eight weeks with 12–62 participants (Alkhawaldeh, 2022; Shi et al., 2026; H. Zhou, 2024), and few with follow-up. Outcomes were heterogeneous: velocity was measured by radar (Aydin et al., 2026), accuracy by target-based or validated strike tests (Chen, 2023; Niyazov et al., 2024; Verma et al., 2026), and coordination by wall-toss or sensor tests. Several trials did not describe randomisation or blinding or report effect sizes (Li & Li, 2024; Liu, 2024; Sm et al., 2025), whereas recent trials and reviews reported effect sizes and maturity covariates (Shi et al., 2026; T. Wang et al., 2025). FICO scores indicated mostly moderate to high quality (17 high, 26 moderate and 1 low-moderate), with weaknesses concentrated in the Context and Outcome dimensions. Where reported, effect magnitudes ranged from small-to-moderate standardised effects of plyometric training on power, agility and speed (Deng et al., 2024) to 57–64% of smash-velocity variance explained by shoulder strength (Aydin et al., 2026) and about 42% of skill-level variance explained by spatial orientation (Jaworski et al., 2021); this heterogeneity of metrics and measurement protocols currently prevents meta-analytic synthesis.

Taken together, jump smash accuracy is best understood as the product of two interacting systems: a force-generating kinetic chain anchored in leg power, trunk stability and shoulder strength, which determines achievable velocity (Aydin et al., 2026; Lin et al., 2025; H. Zhou, 2024), and a perception–action system reflected in hand–eye coordination, visual attention and spatial orientation, which determines whether that velocity reaches the target (Jaworski et al., 2021; Ochor & Amasiatu, 2025). Within this dual-system framework, the force system comprises the lower-limb, trunk and upper-limb capacities that generate and transfer impulse along the kinetic chain, whereas the control system comprises the perceptual and visuomotor processes that calibrate timing, contact location and racket-face orientation to the target. The two systems interact: greater available force allows a given shot speed to be produced at a lower proportion of maximal effort, leaving more capacity for control, whereas fatigue or cognitive load in either system degrades the output of the other. The framework differs from classic kinetic-chain models, which explain velocity but are silent on target precision, and from the speed–accuracy trade-off (Fitts, 1954), which treats speed and accuracy as competing; here, force reserve is proposed to relax that trade-off. It is compatible with dynamical systems accounts of coordination, as illustrated by the fatigue-related increase in lower-limb synergies (Z. Zhou et al., 2025), but adds an explicit and testable outcome hierarchy. Because no included study measured all three determinants simultaneously, the framework is a theoretical synthesis awaiting empirical validation rather than an established causal model. Strength without control produces fast but erratic shots; control without strength produces accurate but non-threatening ones.

This is consistent with combined interventions such as Shuttle Time and technical plyometrics improving both physical and stroke outcomes (Niyazov et al., 2024; Shi et al., 2026). Theoretically, the findings extend kinetic-chain models to landing-point stability and accuracy, and support perception–action accounts of calibrated action capabilities (Zhang et al., 2024) and the psychobiological model of mental fatigue (C. Ding et al., 2024). Compared with prior single-modality reviews of resistance, plyometric, core, stroboscopic and mental-fatigue research (Deng et al., 2024; Ren et al., 2025; Yu et al., 2026), this review places accuracy rather than fitness at the centre. Unlike the meta-analyses of plyometric and core training, which reported small-to-moderate effects on power, agility and balance without accuracy outcomes (Deng et al., 2024; Ma et al., 2024), and the resistance-training review that found limited smash evidence (T. Wang et al., 2025), the present synthesis shows where accuracy has and has not been measured; and in contrast to profile reviews that rank capacities by level (Guarnieri et al., 2026) or fatigue reviews that focus on cognition (C. Ding et al., 2024; da Costa et al., 2022), it links both streams to a single stroke outcome. Apparent contradictions, such as secondary explosive strength in table tennis versus strong strength–velocity links in badminton (Aydin et al., 2026; Horníková, 2022), likely reflect sport-specific demands; and BFRT improving accuracy where caffeine did not suggests that accuracy responds more to training-induced adaptation than to acute arousal.

Practically, coaches should combine shoulder-focused strength and upper-limb plyometrics (Shi et al., 2026; Verma et al., 2026) with lower-limb plyometric and core training (Deng et al., 2024; Ma et al., 2024) and visuomotor methods such as quantitative feedback, mixed-reality or stroboscopic training (Ren et al., 2025; Suh & Jeong, 2025). Accuracy should be trained and tested under physical and mental fatigue (Alkhawaldeh, 2022; Habay et al., 2021); programmes should be individualised to maturity and sex (Pambudi et al., 2025; Weng et al., 2025), monitor shoulder asymmetry and trunk mobility (Nageswari et al., 2026; X. Zhou et al., 2022) and maintain visuomotor work continuously (Chang et al., 2022). Shoulder strength, spatial orientation and visual reaction time appear informative for talent identification. This review is limited by searching only Scopus, restricting inclusion to English-language 2021–2026 articles, the heterogeneity that precluded meta-analysis and the inclusion of non-badminton studies. These limitations have direct consequences: relevant studies indexed only in SPORTDiscus or regional databases, and non-English studies from Asian and Eastern European badminton nations, may have been missed, and the geographic concentration of the evidence restricts generalisability to non-Asian players. Future research should conduct adequately powered randomised trials of eight weeks or longer comparing combined and single-component programmes with jump smash velocity and accuracy as co-primary outcomes; validate a standardised jump smash accuracy test usable in fresh and fatigued states; apply multivariable, structural equation or mediation models; and include female, youth and non-Asian samples stratified by maturity and level, with measures of anxiety and mental fatigue. As minimum standards, correlational studies should recruit at least 85 participants to detect a moderate association ($r = 0.30$, $\alpha = .05$, power = .80), trials should report a priori power calculations, control groups and effect sizes with confidence intervals, and accuracy tests should demonstrate test–retest reliability of ICC ≥ 0.75.

Conclusions

This review of 44 studies published between 2021 and 2026 suggests that jump smash accuracy in badminton results from the interaction of force production and perceptual-motor control rather than any single capacity. Arm muscle strength, especially at the shoulder, is the most consistent physical correlate of smash velocity, explaining 57–64% of its variance in young players, and responds to targeted upper-limb training, whereas leg explosive power improves reliably with plyometric and neuromuscular training (small-to-moderate effects) but appears to contribute to accuracy mainly through a stable trunk and efficient energy transfer. Hand–eye coordination and visuomotor control show the most direct association with striking precision, with spatial orientation alone explaining about 42% of skill-level variance in elite players, and can be enhanced through feedback-rich, immersive and visual training. These determinants appear to operate within an integrated kinetic chain whose output is moderated by muscular and mental fatigue, maturation, sex and shoulder health. The proposed contribution is a dual-system framework, in which a force system sets the attainable velocity and a perception–action control system governs whether that velocity reaches the target; because the evidence is correlational, fragmented and measured with heterogeneous instruments that precluded meta-analysis, this framework remains a theoretical synthesis awaiting empirical validation. Coaches may combine shoulder-focused strength, lower-limb and core power and visuomotor training, individualise programmes and rehearse accurate smashing under fatigue. Future studies should measure all three determinants and smash accuracy together in randomised or multivariable designs with a priori power analysis (at least 85 participants for moderate correlations), control groups and accuracy tests with reliability of ICC ≥ 0.75.

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