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Biomechanics of the Tennis Serve: A Systematic Review of Kinematic, Kinetic, and Neuromuscular Evidence

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ADMINISTRATIVE INFORMATION

Support - No.

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Conflicts of interest - None declared.

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Amendments - This protocol was registered with the International Platform of Registered Systematic Review and Meta-Analysis Protocols (INPLASY) on 5 February 2026 and was last updated on 5 February 2026.

INTRODUCTION

Review question / Objective Population: Human tennis players (no restrictions on sex, age, or playing level).

Intervention/Exposure & Comparator: Performance of the tennis serve under different conditions (e.g., serve type, task constraints, or fatigue status), with comparisons across conditions/groups when available.

Outcomes: Quantitative biomechanical outcomes during the serve, including kinematic variables (joint angles, angular velocities, segment rotations), kinetic variables (e.g., ground reaction forces, joint moments/torques where available), neuromuscular outcomes (surface EMG), and related measures such as plantar pressure; outcomes linked to performance (e.g., ball/racket speed) and joint loading distribution are of interest.

Study design: Peer-reviewed experimental or observational studies in humans reporting at least one quantitative biomechanical outcome during the tennis serve.

Objectives:

This systematic review aims to synthesize kinematic, kinetic, and neuromuscular evidence on the tennis serve through narrative synthesis due to heterogeneity in instrumentation, modeling, and reporting. Specifically, we will:

- (1) describe participant and study characteristics and assess representativeness;
- (2) summarize measurement modalities and protocols, highlighting methodological strengths and limitations;
- (3) synthesize phase-based biomechanics of the serve to identify consistent whole-body mechanisms across the lower limb–trunk–upper limb kinetic chain; and
- (4) examine how serve type, task constraints, skill level, and fatigue influence performance-related outcomes and the distribution of mechanical loads relevant to injury risk, and identify key evidence gaps to guide training, load management, and future research standardization.

Rationale The tennis serve is a high-velocity, whole-body movement that is critical for performance and is also a common context for overuse injuries. Generating high ball and racket speeds requires rapid energy transfer along the lower limb–trunk–upper limb kinetic chain, which may increase mechanical demands on the shoulder, elbow, and trunk. Accordingly, understanding serve biomechanics is essential for optimizing performance while managing mechanical loads that may contribute to injury risk.

Although a substantial body of research has examined tennis serve biomechanics, the evidence is fragmented across multiple measurement modalities (3D motion capture, force platforms, inverse dynamics, surface EMG, plantar pressure, and related approaches) and is characterized by considerable heterogeneity in serve phase definitions, instrumentation, modeling assumptions, outcome selection, and reporting conventions. These inconsistencies hinder meaningful comparisons between studies and reduce the clarity of actionable conclusions for coaches, clinicians, and researchers. In addition, study samples may not be fully representative of the broader tennis population (e.g., limited data in female athletes, adolescents, and lower-level players), and the biomechanical effects of serve type (flat/topspin/slice), task constraints (targeting, ecological setting), skill level, and fatigue have not been comprehensively integrated.

A systematic review is therefore warranted to consolidate and critically appraise the existing biomechanical evidence on the tennis serve. By applying predefined eligibility criteria and a transparent search strategy, assessing risk of bias/quality, and synthesizing findings within a coherent phase-based framework, this review will clarify areas of agreement and uncertainty across kinematic, kinetic, and neuromuscular outcomes. The review will also highlight methodological gaps (e.g., limited loading estimates, inconsistent phase definitions, and variable ecological validity) and provide recommendations for standardizing future study designs and reporting. Ultimately, the synthesized evidence can inform technique optimization, training prescription, and injury-prevention strategies, while guiding future research toward more comparable and clinically meaningful biomechanical outcomes.

Condition being studied This review focuses on the biomechanics of the tennis serve in human tennis players. The condition/topic of interest is the phase-based whole-body kinematic, kinetic, and neuromuscular characteristics of the serve,

including how different serve types, task constraints, skill level, and fatigue influence performance-related outcomes (e.g., ball/racket speed) and the distribution of mechanical loads that may be relevant to injury risk.

METHODS

Search strategy We will conduct systematic searches in the following electronic databases from inception to 10 November 2025: PubMed, Embase, Web of Science, and Scopus. We will also perform backward and forward citation tracking of all included studies and relevant reviews to identify additional eligible records.

The search strategy will combine controlled vocabulary (e.g., MeSH/Emtree where applicable) and free-text terms related to (1) tennis and the serve, and (2) biomechanics and measurement modalities. Core concepts will include:

Sport/task terms: “tennis”, “serve”, “service”, “serving”, “overhead”, “overarm”. Biomechanics terms: “biomechanic*”, “kinematic*”, “kinetic*”, “inverse dynamic*”, “joint moment*”, “joint torque*”, “ground reaction force*”, “GRF”, “plantar pressure”, “force plate”, “motion capture”, “3D”, “three-dimensional”, “electromyograph*”, “EMG”, “neuromuscular”, “muscle activation”, “segment*”, “joint angle*”, “angular velocity”, “trunk rotation”, “shoulder”, “elbow”, “lumbar”, “lower limb”.

An example PubMed strategy will follow this structure:

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(tennis[Title/Abstract] OR tennis[MeSH]) AND (serve*[Title/Abstract] OR service[Title/Abstract] OR serving[Title/Abstract]) AND (biomechanic*[Title/Abstract] OR kinematic*[Title/Abstract] OR kinetic*[Title/Abstract] OR electromyograph*[Title/Abstract] OR EMG[Title/Abstract] OR “ground reaction force”[Title/Abstract] OR plantar pressure[Title/Abstract] OR “motion capture”[Title/Abstract] OR “inverse dynamics”[Title/Abstract]).
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Search strings will be adapted to each database’s syntax and indexing. Records will be exported to a reference manager, duplicates removed, and then screened by title/abstract and full text against predefined eligibility criteria.

Participant or population Human tennis players performing the tennis serve. We will include participants of any sex, age group (adolescents and adults), and playing level (recreational, intermediate, competitive, elite), provided the study reports at least one quantitative biomechanical outcome during the serve. Studies in non-human models, simulations without human participants, or non-tennis populations will be excluded.

Intervention Not applicable in the clinical sense. The “intervention/exposure” is the performance of the tennis serve under defined experimental or observational conditions. This includes studies evaluating the serve in different contexts such as: different serve types (e.g., flat, topspin/kick, slice), different task constraints (e.g., target zones, instructed speed/accuracy, laboratory vs on-court settings), different fatigue states (pre/post match, prolonged play, or fatigue protocols), and/or comparisons across skill levels, sex, or other participant characteristics.

Comparator Within-participant comparisons across serve types (flat vs topspin/kick vs slice), conditions (e.g., accuracy vs power instructions), task constraints (targeting vs non-targeting), or fatigue status (pre- vs post-fatigue/match); between-group comparisons (e.g., elite vs sub-elite/recreational; male vs female; injured vs non-injured where reported); and/or comparisons across measurement modalities or analysis approaches when the same task is assessed using different biomechanical methods. If a study is purely descriptive without an explicit comparator, it will still be eligible provided it reports quantitative biomechanical outcomes during the tennis serve.

Study designs to be included Experimental and observational human studies reporting quantitative biomechanical outcomes during the tennis serve, including cross-sectional laboratory or on-court studies, within-subject condition comparisons (e.g., serve type/fatigue), and between-group comparisons (e.g., skill level/sex). Case reports, reviews, editorials, conference abstracts, theses, and non-human or simulation-only studies will be excluded.

Eligibility criteria Studies will be included if they meet all of the following criteria:
 Population: Human tennis players (any sex, age, or playing level).
 Task: The study assesses the tennis serve (any serve type) performed as an overhead/overarm serving action in tennis.
 Outcomes: Reports at least one quantitative biomechanical outcome during the serve, including kinematics (e.g., joint/segment angles, velocities), kinetics (e.g., ground reaction forces, joint moments/torques derived during the serve), neuromuscular outcomes (surface EMG), and/or plantar pressure. Studies reporting strength/capacity correlates (e.g., isokinetic shoulder torque) will be eligible if clearly linked to serve performance or serving mechanics.

Study type: Peer-reviewed full-text articles (experimental or observational designs).
 Language: English.
 Exclusion criteria:
 Non-human studies, purely computational/simulation studies without human participants, and studies not involving the tennis serve.
 Non-original articles (reviews, meta-analyses, scoping reviews), editorials, letters, protocols, conference abstracts, dissertations/theses, and other grey literature.
 Studies that do not provide extractable quantitative biomechanical outcomes related to the serve.

Information sources Electronic databases to be searched from inception to 10 November 2025 will include PubMed, Embase, Web of Science, and Scopus. We will additionally perform backward (reference list) and forward (citation) searching of all included studies and relevant reviews to identify further eligible records. Searches will use a combination of controlled vocabulary and free-text terms related to tennis serving and biomechanics. We will not routinely search trial registries because this review focuses on biomechanical observational/experimental studies rather than clinical trials. We will not include conference abstracts or theses/dissertations as eligible sources; however, when key methodological details or outcomes are unclear, we may contact corresponding authors of included studies to request clarification.

Main outcome(s) Primary outcomes are quantitative biomechanical variables measured during the tennis serve, including:
 Kinematics: joint/segment angles, ranges of motion, angular velocities/accelerations, segment rotations (lower limb, pelvis/trunk, shoulder, elbow, wrist).
 Kinetics: ground reaction forces, plantar pressure metrics, and joint moments/torques or related inverse-dynamics estimates reported for the serve phases where available.
 Neuromuscular: surface EMG outcomes (e.g., activation timing, amplitude/normalised EMG, co-contraction) of relevant muscle groups.
 Performance-related variables (e.g., ball speed, racket speed) and load distribution patterns relevant to injury risk will be synthesised when reported.

Quality assessment / Risk of bias analysis Risk of bias (study quality) will be assessed independently by two reviewers using the Crombie criteria (7 domains) commonly applied in sports biomechanics reviews. The domains cover: (1)

study aim clearly stated; (2) appropriateness of study design; (3) participant selection/representativeness; (4) adequacy of outcome measurement (validity/reliability and reporting); (5) appropriateness of statistical analysis; (6) control of confounding factors (where applicable); and (7) reporting of sample size justification/power (or equivalent methodological justification).

Each domain will be rated as Yes, No, or Unclear. For scoring, Yes = 1, No = 0, and Unclear = 0.5, yielding a total score from 0 to 7. Studies will then be categorised as: A (low risk of bias/high quality) if score > 5.5; B (moderate risk of bias/moderate quality) if score 3.5–5.5; and C (high risk of bias/low quality) if score < 3.5. Disagreements will be resolved through discussion, and if consensus cannot be reached, a third reviewer will arbitrate. Inter-rater agreement will be reported (e.g., percent agreement).

Strategy of data synthesis Due to anticipated heterogeneity in participant characteristics, serve phase definitions, measurement modalities, modeling assumptions (e.g., inverse dynamics), and outcome reporting, the primary synthesis will be narrative with structured tabulation.

We will extract and summarise data by: (1) serve phase (using a unified phase-based framework where possible), (2) body region/kinetic chain (lower limb, trunk/pelvis, shoulder, elbow, wrist/hand), and (3) measurement modality (kinematics, kinetics, neuromuscular/EMG, plantar pressure). For each domain, we will report direction and magnitude patterns (when comparable), highlight consistent findings across studies, and explicitly note conflicting results.

When studies are sufficiently comparable (same outcome definition, similar phase/event definition, comparable units and statistics), we will consider quantitative pooling; however, we anticipate that meta-analysis may not be feasible for most outcomes. Where pooling is not possible, we will use vote-counting based on direction of effect supplemented by effect estimates and confidence intervals where reported, and we will prioritise higher-quality evidence in interpretation.

We will also synthesise determinants/moderators (serve type, task constraints, skill level, fatigue, sex, and ecological setting) and discuss how these factors influence performance-related variables (e.g., ball/racket speed) and load distribution patterns relevant to injury risk. The strength of inferences will be interpreted in light of risk-of-bias ratings and methodological limitations (e.g., sample size, representativeness, and measurement/modeling assumptions).

Subgroup analysis Planned subgroup analyses (where data permit) include:

Serve type (e.g., flat vs topspin/kick vs slice).

Skill level (elite/competitive vs sub-elite/recreational).

Sex (male vs female), if sufficient studies report sex-stratified results.

Fatigue status (pre- vs post-fatigue/prolonged play or match).

Task constraints / ecological validity (laboratory vs on-court; instructed speed vs accuracy/targeting).

Measurement modality / modeling approach (e.g., different marker sets, inverse dynamics assumptions, EMG normalisation procedures) when these are likely to explain heterogeneity.

Subgroup analyses will be primarily qualitative/structured narrative comparisons. If quantitative synthesis is feasible for a given outcome, subgroup analyses will be conducted by stratifying pooled estimates accordingly.

Sensitivity analysis Not applicable. We did not plan to conduct sensitivity analyses because quantitative pooling (meta-analysis) is not expected to be feasible given substantial heterogeneity in outcome definitions, serve phase/event definitions, instrumentation, and reporting across included biomechanical studies.

Country(ies) involved China.

Keywords Tennis serve; biomechanics; kinematics; kinetics; electromyography; kinetic chain; joint loading.

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