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Principles Of Systematizing Kinematic Indicators Of Table Tennis Players

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Abstract
The article concludes that a principled systematization enables coaches and researchers to compare findings across studies, design targeted interventions, and accommodate individual technical signatures without sacrificing analytical rigor.

Keywords: table tennis, kinematics, systematization, biomechanics, movement variability, performance analysis

Introduction

Kinematic analysis of table tennis has expanded rapidly, driven by advances in motion capture technology, computer vision, and wearable sensing. Studies now routinely quantify joint angles, segment velocities, and landmark trajectories during strokes. However, this proliferation of data has not been matched by a corresponding clarity in how kinematic indicators should be organized, compared, and interpreted across studies. Different investigations adopt different marker sets, phase definitions, parameter naming conventions, and statistical treatments, making synthesis difficult and practical application inconsistent.

The problem is particularly acute in table tennis because of the sport's distinctive biomechanical demands. Strokes are executed at high frequency, with movement cycles often lasting approximately one second or less. The upper limb's striking action is tightly coupled with lower-limb footwork and rapid repositioning, meaning that single-stroke laboratory analyses may not capture the coordinative demands of actual play. Furthermore, players exhibit what has been termed "functional movement variability"—different joint configurations producing similar hand velocities—which complicates any attempt to define a single "correct" kinematic profile.

This article addresses the question of how kinematic indicators for table tennis players should be systematized. It proposes four organizing principles derived from the current research literature and evaluates the evidence supporting each.



Principle 1: Hierarchical Organization of Parameters

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The first principle concerns the vertical structure of kinematic data. Recent work has adopted a three-tier hierarchy that moves from global to local: **landmark parameters** (position and velocity of body landmarks such as the shoulder, elbow, wrist, and hips), **segment parameters** (angular range and angular velocity of body segments such as the shoulder line and hip line), and **joint parameters** (joint-specific angular range and angular velocity, treated as scalar quantities) .

This hierarchy has analytical value because different tiers answer different questions. Landmark velocities describe the gross movement of body parts through space and are directly interpretable by coaches. Segment rotations capture the coordinative sequencing between upper and lower body—for example, the finding that shoulder-line rotation correlates with ball speed at r = 0.54–0.57, while hip-line rotation correlates at r = 0.51–0.59 . Joint angles provide the finest resolution and are most useful for identifying technical deficiencies or injury-risk patterns, such as the finding that elbow angle decreases from approximately 111° at backswing to approximately 94° at impact in the forehand counter drive .

A systematization that preserves this hierarchy allows researchers to select the appropriate resolution for their question while maintaining traceability to other levels. It also facilitates communication between biomechanists, who may prioritize joint-level data, and coaches, who typically work with observable landmark movements.

Principle 2: Phase-Specific Decomposition

The second principle requires that kinematic indicators be referenced to defined movement phases. Table tennis strokes are not homogeneous events; the backswing, forward swing, impact, and follow-through involve distinct neuromuscular and biomechanical demands. Research has demonstrated that parameters extracted at different phases yield different and sometimes opposing relationships with performance outcomes.

For example, in the forehand stroke, ball speed correlates positively with the playing-side elbow's positional range (r = 0.63) and mean velocity (r = 0.70) during the forward swing, but negatively with elbow flexion-extension range (r = −0.35) . Without phase specification, such findings would appear contradictory. Similarly, the forehand counter drive exhibits its fastest racket-head velocity at impact, with horizontal velocity of approximately 7,796 mm/s and vertical velocity of approximately 4,589 mm/s . Reporting these values without indicating that they represent the impact instant would render them meaningless for comparison.

Phase-specific decomposition also accommodates the sport's temporal constraints. In combination play—where multiple topspin strokes are linked by footwork—the ranges of motion in specific body segments are reduced, sometimes by several dozen degrees, compared with single-stroke executions . A systematization that does not distinguish between isolated strokes and combination strokes will therefore conflate two distinct kinematic regimes.

Principle 3: Outcome-Linked Selection of Indicators

The third principle holds that kinematic indicators should be selected and prioritized according to their demonstrated relationship with performance outcomes, principally ball speed and accuracy. Not all measurable parameters are equally informative, and an exhaustive catalog of every possible angle and velocity produces data without insight.

Recent correlation analyses provide empirical guidance for this selection. In a study of 34 female players aged 9.1–21.7 years, ball speed increased with greater linear movement at the playing-side shoulder (r = 0.51–0.63), elbow (r = 0.63–0.70), and wrist (r = 0.50–0.60), and with enhanced rotational motion at the upper arm (r = 0.65–0.71), shoulder line (r = 0.54–0.57), and hip line (r = 0.51–0.59). Conversely, ball speed decreased with excessive contralateral shoulder horizontal flexion/extension (r = −0.44 to −0.62) and playing-side elbow flexion-extension (r = −0.35) .

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These findings suggest a prioritized indicator set: playing-side upper-arm rotation, elbow linear velocity, and shoulder-line rotation should be considered primary indicators for ball speed, while contralateral shoulder motion and elbow flexion range serve as secondary indicators of potentially counterproductive patterns. Such evidence-based prioritization is more useful to coaches than a comprehensive but undifferentiated parameter list.

Outcome linkage must also account for developmental factors. The same study found that ball speed increases with age before approximately 14.3 years (between-subject r = 0.68) but plateaus thereafter (r = 0.17) . This suggests that kinematic indicators for pre-adolescent players should be interpreted differently from those of mature athletes, and that systematization must include age-referenced norms rather than universal benchmarks.

Principle 4: Variability-Aware Interpretation

The fourth principle concerns how variability across and within players is treated. Traditional biomechanical analysis often treats variation as error to be minimized. Table tennis research, however, indicates that variability can be functional: advanced players achieve similar maximum hand velocities through different joint configurations, adapting their movement patterns to contextual demands .

This has direct implications for systematization. First, group-level averages may obscure meaningful individual signatures; a kinematic profile that is "average" may correspond to no actual player. Second, intervention studies should report individual response patterns alongside group statistics. Third, the systematization should distinguish between variability that reflects adaptive flexibility (functional) and variability that reflects inconsistency or technical error (dysfunctional)—a distinction that requires coupling kinematic data with outcome measures such as accuracy and consistency.

The combination-stroke study illustrates this principle concretely. Even among eight national-team-level players performing the same topspin combination, execution patterns differed in joint angles, yet the maximum linear velocity of the playing hand was similar across players . A systematization that ranked players by similarity to a single template would misrepresent this functional equivalence.

Discussion

The four principles proposed here are interrelated rather than independent. Hierarchical organization provides the structural framework; phase decomposition supplies the temporal reference; outcome linkage determines which parameters within that structure and at which phases deserve attention; and variability-aware interpretation governs how the resulting data are aggregated and applied.

Several limitations in the current evidence base should be acknowledged. Most kinematic studies involve small samples—the MediaPipe study analyzed 34 players, and the combination-stroke study involved eight . Marker-based motion capture, while accurate, requires laboratory conditions that may not reflect competitive play. Emerging approaches such as MediaPipe-based single-camera analysis and physics-informed neural networks offer lighter-weight alternatives, but their validity against marker-based systems requires further confirmation . The systematization principles proposed here should therefore be regarded as provisional and subject to refinement as data from larger, more ecologically valid studies become available.

A further consideration concerns the relationship between kinematic indicators and injury risk. The current literature focuses predominantly on performance outcomes. The finding that elbow flexion-extension correlates negatively with ball speed raises the question of whether technical patterns optimized for speed also distribute joint loading appropriately. A complete systematization would ideally incorporate load-related indicators, but the evidence base for this dimension in table tennis remains underdeveloped.

Conclusion

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The systematization of kinematic indicators for table tennis players should proceed according to four principles: hierarchical organization from landmarks to joints, phase-specific decomposition of strokes, outcome-linked selection of parameters, and variability-aware interpretation that distinguishes functional from dysfunctional variation. These principles are grounded in recent empirical findings on the relationships between kinematic parameters and ball speed, the phase-dependent nature of those relationships, and the documented presence of functional movement variability among advanced players. Adopting a principled systematization would improve comparability across studies, support evidence-based coaching decisions, and accommodate individual technical signatures without abandoning analytical rigor. Future research should prioritize larger samples, ecologically valid data collection, and the integration of load-related indicators alongside performance measures.

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