TYPE Original Research Articles
DOI 10.53905/Activein.v1i02.13

OPEN ACCESS

EDITED BY
Dr. Farid M. Alhumary, M.Pd
Fakultas Keguruan & Ilmu Pendidikan, Universitas Pembinaan Masyarakat Indonesia.

CORRESPONDENCE
Adelia Tri Septiana Sirait
adeliasirait03@gmail.com

ARTICLE HISTORY
Received: February 18, 2026
Accepted: April 19, 2026
Published: April 18, 2026

CITATION (APA STYLE 7):
Sirait, A. T. S., Hutabarat, I. I., Sinaga, K. S., Siregar, L. A., & Siregar , S. (2026). Integrating Footwork-Based Training into the Junior High School Physical Education Curriculum: An Experimental Study on Forehand Drive Accuracy in Table Tennis. *IGI in Education Insight*, 1(02), 101-107. https://doi.org/10.53905/edu.v1i02.13

Integrating Footwork-Based Training into the Junior High School Physical Education Curriculum: An Experimental Study on Forehand Drive Accuracy in Table Tennis

Adelia Tri Septiana Sirait*[1], Indah Indriyani Hutabarat[1], Keleo Setrika Sinaga[1], Lola Andriani Siregar[1], Samsudin Siregar[1]

[1]Faculty of Sport Science, State University of Medan, Indonesia.

ABSTRACT
Purpose of the study: This study examined the effectiveness of a structured footwork-based training (FBT) programme integrated into the junior high school physical education (PE) curriculum in improving forehand drive accuracy among adolescent table tennis players.
Materials and methods: A randomized controlled experimental design with pre-test and post-test measurements was employed. Sixty students aged 13–15 years from selected junior high schools in Medan, North Sumatra, Indonesia, were randomly assigned to an experimental group (EG; n = 30) and a control group (CG; n = 30). The EG participated in an eight-week FBT programme conducted three times per week (90 minutes per session), while the CG followed the standard PE curriculum. Forehand drive accuracy was measured using the validated Backboard Test for Table Tennis adapted to the Indonesian school context (20-point scale). Data were analyzed using Shapiro–Wilk tests, paired-samples t-tests, independent-samples t-tests, and Cohen's d effect sizes.
Results: The EG demonstrated a significant improvement in forehand drive accuracy, increasing from a pre-test mean of 10.47 (SD = 1.82) to a post-test mean of 15.93 (SD = 1.67), $t(29) = 18.43$, $p < .001$, $d = 3.14$. In contrast, the CG showed only a small, non-significant increase from 10.53 (SD = 1.79) to 11.17 (SD = 1.88), $p = .092$. Post-test comparisons revealed a significant advantage for the EG over the CG, $t(58) = 11.74$, $p < .001$, $d = 2.94$. The intervention explained approximately 52% of the variance in post-test accuracy scores.
Conclusions: Integrating footwork-based training into PE lessons substantially improves forehand drive accuracy in junior high school table tennis learners. The findings reinforce the importance of movement efficiency as a prerequisite for stroke proficiency and provide practical evidence for PE teachers, coaches, and curriculum developers seeking to enhance skill acquisition in school-based table tennis programmes.

Keywords
footwork training; forehand drive; table tennis; physical education curriculum; junior high school; motor learning; sport pedagogy.

INTRODUCTION
Contextual Framework: Table Tennis in School Physical Education

Table tennis is one of the most globally practised racquet sports, with an estimated 300 million active participants across more than 226 affiliated national associations under the International Table Tennis Federation (Federation, 2023). Beyond its competitive dimensions, the sport has been increasingly recognised within school-based physical education (PE) contexts as a vehicle for developing fine motor coordination, reaction time, spatial anticipation, and cardiovascular fitness in adolescent populations (Djokic & Munivrana, 2021; Kondrič et al., 2013). In Indonesia, table tennis occupies a prominent position within the national PE curriculum at the junior high school (Sekolah Menengah Pertama, SMP) level, mandated under the 2022 Kurikulum Merdeka framework, which emphasises the development of foundational sport competencies through movement-centred pedagogical approaches (Prasetyo & Sari, 2025) .

Despite its curricular prominence, pedagogical research on effective instructional methods for table tennis at the school level remains comparatively sparse, particularly in Southeast Asian educational contexts (Hao et al., 2014; Zagatto et al., 2016). The preponderance of extant intervention studies has been conducted within elite or sub-elite competitive settings, and their findings may not be generalisable to novice learners in compulsory school PE contexts, where constraints of time, equipment, class size, and teacher expertise impose significant pedagogical challenges (Zeng et al., 2019). A critical and underexplored dimension of school-level table tennis instruction pertains to the role of footwork: the coordinated lower-body movement system that positions the player optimally in relation to the incoming ball prior to stroke execution.

Critical Examination of Existing Literature

Footwork in racquet sports encompasses a multifaceted set of locomotor and positioning behaviours, including split-step initiation, lateral shuffle, cross-step, and recovery steps, that collectively determine a player's capacity to engage the ball at an optimal contact point (Bankosz & Winiarski, 2018; Munivrana et al., 2015). In table tennis specifically, the relationship between footwork efficiency and stroke quality has been theoretically articulated through the kinematic chain model, which posits that proximal segment stability and positioning constitute necessary preconditions for the generation of distal force and directional accuracy at the paddle (Iino & Kojima, 2009; Qian et al., 2016). Empirical support for this model has been provided by biomechanical analyses demonstrating that players who achieve correct foot-stance prior to stroke execution exhibit significantly greater forehand drive velocity and target accuracy than those who execute strokes from suboptimal positions (Bańkosz & Winiarski, 2018; Fu et al., 2018).

Within the motor learning literature, the acquisition of footwork patterns has been examined through the lens of ecological dynamics theory, which emphasises the role of repetitive interaction between the learner, the task, and the environment in shaping movement solutions (Chow et al., 2015; Renshaw et al., 2019). From this perspective, practice tasks that systematically challenge the learner to coordinate footwork with stroke execution are expected to accelerate the perception-action coupling necessary for automated, accurate performance. Skill-based games approaches and constraints-led instruction have gained traction as delivery models in school PE, yet their explicit application to footwork-centred table tennis pedagogy remains insufficiently documented in the peer-reviewed literature (Araújo & Davids, 2016; Pill, 2018).

The forehand drive, characterised as a fundamental offensive stroke performed with a forward and upward racquet motion from the forehand side, is typically the first advanced stroke introduced to novice players and serves as the technical foundation upon which more complex strokes are progressively built (Fuchs et al., 2018; Lanzoni et al., 2013). Accuracy in the forehand drive is conventionally operationalised as the player's capacity to direct the ball to a predefined target zone with consistency across repeated trials, and constitutes a critical criterion in both formative and summative PE assessments in the Indonesian curriculum (Mahardika et al., 2022, p. 4; Puspitasari et al., 2021). Studies that have evaluated forehand drive accuracy as a dependent variable have predominantly recruited participants from sport-specific training programmes rather than from general school PE cohorts, leaving a substantive gap in the literature concerning the efficacy of curriculum-embedded interventions for this skill domain.

Identification of Research Gaps

A systematic review of the relevant literature reveals at least four interrelated lacunae that the present investigation is designed to address. First, whereas footwork training has been investigated in relation to stroke speed and tactical decision-making in competitive players, its specific contribution to forehand drive accuracy among novice adolescent learners in school PE settings has not been empirically established (Djokic & Munivrana, 2021; Zagatto et al., 2016). Second, the majority of published intervention studies have been conducted over periods of fewer than six weeks, which may be insufficient to detect durable skill consolidation effects; an eight-week protocol affords a more ecologically valid timeline consistent with a typical school PE unit (Hao et al., 2014). Third, there is a paucity of experimental evidence from Indonesian school contexts, where specific ecological conditions—including court dimensions, equipment quality, class size norms, and curriculum scheduling—may modulate the generalisability of findings from Western or East Asian studies. Fourth, no previous study has employed a randomised controlled design to isolate the specific contribution of footwork-based training (as opposed to general table tennis practice) to accuracy improvement, leaving the causal inference structure of prior quasi-experimental findings open to confounding.

Rationale and Study Objectives

The present study was designed to address these gaps by evaluating the effects of a purposefully constructed, footwork-based training programme integrated into the existing junior high school PE curriculum in Medan City, Indonesia, on the forehand drive accuracy of adolescent learners. The intervention was grounded in theoretical principles drawn from motor learning theory, ecological dynamics, and sport pedagogy, and was implemented under ecologically realistic school conditions by certified PE teachers. The study was further motivated by the practical imperative to equip Indonesian PE professionals with evidence-based pedagogical strategies that align with the competency objectives of the national curriculum.

The primary objective of this study was to determine the effect of an eight-week footwork-based training (FBT) programme on forehand drive accuracy in junior high school students enrolled in PE classes in Medan City. The secondary objective was to compare accuracy improvements between the FBT experimental group and a control group receiving standard PE instruction. It was hypothesised that (H_1) students in the FBT experimental group would demonstrate a statistically significant improvement in forehand drive accuracy from pre-test to post-test, and (H_2) the magnitude of improvement in the experimental group would be significantly greater than that observed in the control group.

MATERIALS AND METHODS

Study Participants

Participants were recruited from three state junior high schools (Sekolah Menengah Pertama Negeri) in Medan City, North Sumatra, Indonesia, selected through cluster sampling on the basis of geographic distribution across the city's administrative districts. Eligibility criteria required participants to be: (i) enrolled in Grade VII or VIII (aged 13–15 years); (ii) currently attending compulsory PE classes; (iii) free from musculoskeletal injury or medical contraindication to vigorous physical activity, as confirmed by school health screening; and (iv) possessed of no prior formal table tennis training (i.e., not enrolled in a school table tennis extracurricular programme or external club). Students were excluded if they had missed more than two sessions of data collection or intervention delivery during the study period.

A total of 60 students (32 males, 28 females; M age = 14.1 years, SD = 0.7) met the inclusion criteria and were enrolled in the study following receipt of informed written assent from participants and informed written consent from parents or legal guardians. Participants were randomly assigned using a computer-generated random sequence (Research Randomizer, v4.0) to the EG (n = 30: 16 males, 14 females) or CG (n = 30: 16 males, 12 females). No statistically significant between-group differences were observed at baseline in age ($t(58) = 0.42$, $p = .677$), body mass index ($t(58) = 0.89$, $p = .376$), or pre-test forehand drive accuracy score ($t(58) = 0.14$, $p = .890$), confirming baseline equivalence. The demographic characteristics of the full cohort are presented in Table 1.

Table 1. Baseline Demographic and Physical Characteristics of Study Participants (N = 60)

Variable	EG (n = 30)	CG (n = 30)	Total (N = 60)	p-value
Age (years)	*14.1 ± 0.8*	*14.1 ± 0.7*	*14.1 ± 0.7*	*.677*
Height (cm)	*158.4 ± 6.2*	*157.9 ± 5.8*	*158.1 ± 5.9*	*.729*
Body mass (kg)	*50.8 ± 7.1*	*51.4 ± 6.9*	*51.1 ± 7.0*	*.739*
BMI (kg/m²)	*20.2 ± 1.8*	*20.6 ± 2.1*	*20.4 ± 1.9*	*.376*
Pre-test score (/20)	*10.47 ± 1.82*	*10.53 ± 1.79*	*10.50 ± 1.80*	*.890*
Sex (M/F)	*16/14*	*16/12*	*32/28*	*.796*

Note. Values expressed as mean ± SD unless otherwise indicated. BMI = body mass index; EG = experimental group; CG = control group. p-values from independent-samples t-tests (continuous) or chi-square tests (sex). EG = Experimental Group; CG = Control Group.

Study Design

This study employed a pre-test–post-test randomised controlled experimental design, in accordance with the CONSORT 2010 guidelines for parallel-group randomised trials adapted for physical education research (Schulz et al., 2010). Participants were randomly allocated to one of two conditions: the footwork-based training experimental group (EG) or the conventional PE instruction control group (CG). Outcome assessments were conducted at baseline (Week 0) and immediately following the intervention period (Week 8). The study was conducted between January and March 2024 within the physical education programme of junior high schools affiliated with the Medan City Education Office.

Study Organisation and Intervention Protocol

The study was executed over an eight-week period, with each group receiving three PE sessions per week of 90 minutes' duration, yielding 24 total instructional sessions. All sessions were delivered by three certified PE teachers (mean teaching experience = 8.3 years, SD = 1.9) who had undergone a structured six-hour pre-study orientation workshop covering: (i) the theoretical rationale for footwork-based training; (ii) standardised delivery of the FBT programme; (iii) fidelity monitoring procedures; and (iv) participant safety protocols.

Experimental Group Footwork-Based Training Programme

The FBT programme was designed in accordance with the progressive overload principle and ecological dynamics theory (Renshaw et al., 2019). Each 90-minute session was structured as follows: 15 minutes warm-up (dynamic stretching, agility ladder drills); 20 minutes isolated footwork skill practice (split-step, lateral shuffle, cross-step, and recovery-step sequences); 30 minutes integrated footwork–stroke coupling tasks (shadow footwork paired with forehand drive execution against multiball feeding); 15 minutes game-based application (structured rally with footwork-cueing constraints); and 10 minutes cool-down and reflection. Across the eight weeks, progressive overload was operationalised through systematic increase in the spatial range of footwork demands (Weeks 1–2: single-direction; Weeks 3–4: bilateral; Weeks 5–6: multidirectional random; Weeks 7–8: match-simulation random). Session fidelity was monitored via structured observation checklists completed by an independent research assistant, and fidelity scores averaged 93.7% (SD = 3.1%) across all EG sessions.

Control Group Protocol

The CG continued with the standard school PE curriculum, which included general table tennis instruction consistent with national PE standards: grip technique, stance, basic forehand and backhand stroke mechanics, and simplified game activities. Footwork was addressed only incidentally, as part of general court positioning guidance, without structured drill sequences or progressive overload. CG sessions were structurally equivalent in duration and frequency to EG sessions to control for total instructional time.

Outcome Measurement: Forehand Drive Accuracy Test

Forehand drive accuracy was assessed using the Table Tennis Forehand Drive Accuracy Test (TT-FDAT), a criterion-referenced instrument validated for use with Indonesian adolescent learners (Puspitasari et al., 2021, 2019). In the TT-FDAT, the participant stands at the baseline and executes 20 forehand drive strokes against a ball fed by an automated multiball feeder at a standardised frequency of 40 balls per minute, targeting a predefined 40 × 40 cm scoring zone marked on the opposite half of the table. Each ball landing in the zone scores one point, yielding a maximum possible score of 20. Test reliability was established in the present sample via test–retest administration with a one-week interval in a pilot cohort (n = 20; Intraclass Correlation Coefficient = .91, 95% CI [.84, .96]). All assessments were administered by trained raters blinded to group assignment.

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics Version 27.0 (IBM Corp., Armonk, NY, USA) with an a priori significance threshold of $\alpha = .05$ (two-tailed). Descriptive statistics (means, standard deviations, ranges) were computed for all continuous variables. The Shapiro–Wilk test was applied to evaluate distributional normality; all variables satisfied the normality assumption ($p > .05$). Homogeneity of variance was assessed using Levene's test prior to independent-samples comparisons. Within-group pre-to-post changes were evaluated using paired-samples t-tests. Between-group post-test differences were evaluated using independent-samples t-tests. Effect sizes were computed as Cohen's d, classified as small ($d < 0.5$), medium ($0.5 \le d < 0.8$), and large ($d \ge 0.8$; Cohen, 1988). The proportion of post-test score variance attributable to group condition was estimated via eta-squared (η^2) from a one-way ANOVA. Statistical power for the primary comparison was estimated post hoc using G*Power 3.1 (Faul et al., 2009).

Ethical Considerations

This study was conducted in full compliance with the principles of the Declaration of Helsinki ("World Medical Association Declaration of Helsinki," 2013) and was reviewed and approved by the Research Ethics Committee of the Faculty of Sport Science, State University of Medan (Universitas Negeri Medan), Medan, North Sumatra, Indonesia (Ethical Approval Reference No.: 023/KEPK-FIK-UNIMED/I/2024, issued January 2024). Prior to enrolment, written informed assent was obtained from all student participants, and written informed consent was obtained from each participant's parent or legal guardian. Participation was entirely voluntary; participants were explicitly informed of their right to withdraw from the study at any time without consequence to their academic standing. All data were anonymised and stored securely in accordance with applicable Indonesian data protection legislation.

RESULTS

Within-Group Pre-Test to Post-Test Changes

Descriptive statistics and inferential comparisons for forehand drive accuracy are presented in Table 2. Within the EG, forehand drive accuracy improved markedly from pre-test (M = 10.47, SD = 1.82) to post-test (M = 15.93, SD = 1.67), representing a mean gain of 5.47 points (52.2% increase). The paired-samples t-test confirmed this improvement as statistically significant: t(29) = 18.43, p < .001, Cohen's d = 3.14, indicating a very large effect. Within the CG, improvement from pre-test (M = 10.53, SD = 1.79) to post-test (M = 11.17, SD = 1.88) was negligible (mean gain = 0.63 points; 6.0% increase), and did not reach statistical significance: t(29) = 1.74, p = .092, d = 0.34. Post hoc statistical power for the primary within-group comparison in the EG was estimated at 1.00, confirming adequate power to detect the observed effect. Levene's test indicated homogeneity of variance at post-test (F(1, 58) = 0.48, p = .491), satisfying the prerequisite for parametric between-group comparison.

Table 2. Pre-Test and Post-Test Forehand Drive Accuracy Scores: Descriptive Statistics and Inferential Comparisons

Group	Pre-test M (SD)	Post-test M (SD)	Mean Gain	t-value	p-value	Cohen's d
Experimental (n = 30)	10.47 (1.82)	15.93 (1.67)	+5.47 (52.2%)	18.43	< .001*	3.14
Control (n = 30)	10.53 (1.79)	11.17 (1.88)	+0.63 (6.0%)	1.74	.092	0.34

Note. Paired-samples t-test; M = mean; SD = standard deviation. * p < .001 (two-tailed).

Between-Group Post-Test Comparison

The independent-samples t-test comparing post-test accuracy scores between the EG (M = 15.93, SD = 1.67) and CG (M = 11.17, SD = 1.88) revealed a statistically significant between-group difference: t(58) = 11.74, p < .001, Cohen's d = 2.94. The EG outperformed the CG by a mean of 4.77 points at post-test. One-way ANOVA confirmed that group condition accounted for a substantial proportion of post-test score variance (η^2 = .703, p < .001), indicating that approximately 70.3% of the variance in post-test forehand drive accuracy was attributable to participation in the FBT programme. Between-group comparisons are summarised in Table 3.

Table 3. Between-Group Post-Test Comparison of Forehand Drive Accuracy

Comparison	EG Post-test M (SD)	CG Post-test M (SD)	Mean Diff.	t (df = 58)	p-value
Forehand Drive Accuracy (/20)	15.93 (1.67)	11.17 (1.88)	4.77	11.74	< .001*

Note. Independent-samples t-test; M = mean; SD = standard deviation; η^2 = .703. * p < .001.

Significant Findings Summary

In summary, the data provide unequivocal support for both study hypotheses: (H_1) the FBT programme produced a statistically significant and practically large improvement in forehand drive accuracy within the EG (d = 3.14); (H_2) the magnitude of improvement in the EG was significantly greater than that observed in the CG at post-test (d = 2.94, η^2 = .703). The convergence of statistical significance, very large effect size, and high explained variance substantiates the conclusion that the FBT programme exerted a genuine and educationally meaningful effect on stroke accuracy outcomes in this population.

DISCUSSION

Interpretation of Findings

The primary finding of this study—that an eight-week footwork-based training programme integrated into the school PE curriculum produced a statistically significant and practically large improvement in forehand drive accuracy (d = 3.14)—represents a substantive contribution to the sport pedagogy and motor learning literature in several respects. Most fundamentally, the findings empirically validate the theoretical premise that positional accuracy, as facilitated by systematic footwork training, is a necessary kinematic antecedent to stroke accuracy in table tennis (Bańkosz & Winiarski, 2018; Iino & Kojima, 2009). When students consistently arrived at the contact point in a mechanically optimal stance, as cultivated by the progressive footwork drills, the degrees of freedom available at the elbow and wrist for stroke control were substantially reduced, enabling more consistent and accurate paddle-to-ball contact (Buszard et al., 2020, p. 3115; Lee et al., 2014, p. 1). This interpretation is congruent with Bernstein's degrees-of-freedom problem and its resolution through coordinative structures in motor learning (Bernstein, 1967; Latash, 2012).

The negligible and non-significant improvement in the CG (d = 0.34, p = .092) further substantiates the specificity of the FBT effect, ruling out maturation, general PE exposure, and test-retest familiarisation as sufficient explanations for the EG gains. The magnitude of the between-group difference at post-test (d = 2.94, η^2 = .703) is notably large relative to comparable intervention studies in racquet sport pedagogy, suggesting that the integration of footwork as a discrete, progressively overloaded competency domain—rather than as an incidental component of stroke practice—may represent a qualitatively distinct and more potent instructional strategy (Broadbent et al., 2014, p. 332; Hacques et al., 2020, p. 1389; Lee et al., 2014, p. 1).

Comparison with Antecedent Studies

The present findings corroborate and extend the work of Hao et al. (2014), who reported significant improvements in stroke accuracy following a six-week systematic training programme in Chinese university students, albeit without a footwork-specific focus. The larger effect size observed in the present study (d = 3.14 versus d = 1.87 in Hao et al.) may reflect the added value of explicitly addressing the kinematic chain from foot to paddle, consistent with arguments advanced by Król et al. (2015) that contemporary table tennis coaching must treat footwork as a primary, not supplementary, technical domain. Similarly, the findings align with (Chen & Jia, 2025), who demonstrated biomechanically that correct lower-limb positioning predicts forehand stroke quality in trained players; the present study extends this association to novice adolescent learners in school settings, indicating the generalisability of the kinematic chain relationship across skill levels. From a curriculum and pedagogy standpoint, the successful delivery of the FBT programme by school-based PE teachers—rather than specialist table tennis coaches—is a particularly noteworthy finding (Tang et al., 2026; Zayas et al., 2025). It suggests that with adequate pre-study training and structured programme materials, school PE professionals possess sufficient competency to implement evidence-based sport-specific interventions, a conclusion consistent with the growing body of evidence supporting teacher-mediated physical literacy programmes in Southeast Asian school systems (Chow et al., 2015; Pill, 2018). This has direct implications for the scalability and sustainability of the intervention within the Indonesian national PE context.

Theoretical and Practical Implications

Theoretically, the findings provide empirical support for the ecological dynamics framework (Araújo & Davids, 2016; Renshaw et al., 2019) as a valid theoretical basis for designing table tennis interventions in school PE. The progressive, constraint-manipulation structure of the FBT programme—which systematically altered the spatial and temporal demands on footwork to scaffold emergent perception-action couplings—aligned with the framework's prescriptions for practice design, and the significant accuracy gains observed suggest that this approach generated more robust motor learning than the exploratory but less structured practice typical of conventional PE instruction (Roberts et al., 2018, p. 167; Warren, 2006, p. 381). Practically, the findings advocate for the incorporation of explicitly structured footwork drill sequences into standard school table tennis units, a recommendation that can be operationalised within the existing Kurikulum Merdeka framework without requiring additional curriculum time, provided that existing forehand stroke practice is reorganised to embed footwork positioning as a primary learning objective.

Limitations

Several methodological limitations warrant acknowledgement. First, the study sample was drawn exclusively from junior high schools in Medan City; the extent to which findings generalise to rural, lower-resource, or differently structured school PE contexts in Indonesia or internationally remains to be established. Second, although sex was balanced across groups, the study was not powered to detect sex-stratified intervention effects; given documented differences in lower-body motor development trajectories between adolescent males and females, future studies should conduct pre-specified subgroup analyses by sex. Third, the absence of a delayed post-test measurement (e.g., at 12 or 24 weeks post-intervention) means that the durability of the observed accuracy improvements cannot be assessed from the present data. Fourth, the Hawthorne effect—whereby participants in the EG may have performed better at post-test partly due to perceived special attention—cannot be fully excluded, although the use of blind assessors and standardised measurement conditions mitigated this risk. Fifth, the study did not include objective kinematic or biomechanical measures of footwork quality, relying instead on accuracy as a behavioural proxy for the underlying movement improvements; future investigations incorporating motion capture or inertial measurement unit technologies would provide more direct evidence of the mechanism of effect.

CONCLUSION

This randomised controlled experimental study provides robust evidence that an eight-week footwork-based training programme, deliberately integrated into the junior high school PE curriculum in Medan City, Indonesia, produces statistically significant and practically large improvements in forehand drive accuracy among adolescent novice table tennis learners ($d = 3.14$). The observed effect was substantially greater than that achieved by conventional PE instruction (between-group $d = 2.94$, $\eta^2 = .703$), and was successfully delivered by school PE teachers following structured preparation, supporting the real-world scalability of the intervention.

These findings reinforce the central theoretical argument advanced in the introduction—that stroke accuracy in table tennis is fundamentally contingent upon positional accuracy, and that positional accuracy is an acquirable competency that responds to systematic footwork-focused instruction. By demonstrating that this relationship holds in school-aged novices as well as in trained players, the study extends the scope of the kinematic chain model and the ecological dynamics framework to encompass school-based sport pedagogy contexts. The results correlate directly with the study's stated hypotheses: H_1 and H_2 were both supported by the data at the $p < .001$ level, with effect sizes of a magnitude that compels pedagogical attention.

For PE curriculum designers and school sport administrators in Indonesia and comparable educational systems, the study's findings constitute actionable evidence for the revision of table tennis instructional units to position footwork training as a primary, progressively structured domain rather than a secondary or implicit adjunct to stroke practice. For the broader sport pedagogy research community, the study highlights the need for randomised controlled designs with footwork-specific outcome measures and the potential value of school PE contexts as ecologically valid laboratories for investigating foundational movement-sport skill acquisition.

The authors recommend that future studies: (i) extend the intervention period to 12 or 16 weeks to investigate skill retention and transfer; (ii) include delayed post-test assessments at 3- and 6-month follow-up points; (iii) incorporate sex-stratified analyses with adequately powered samples; (iv) integrate biomechanical measures of footwork quality alongside behavioural accuracy outcomes; (v) replicate the investigation across rural and urban school contexts and across multiple Indonesian provinces to establish national generalisability; and (vi) examine the moderating roles of baseline motor proficiency, physical fitness level, and prior sport participation experience on FBT responsiveness.

Acknowledgements

The authors express sincere gratitude to the principals, PE teachers, and students of the participating junior high schools in Medan City for their generous cooperation and commitment throughout the study. The authors also thank the research assistants from the Faculty of Sport Science, State University of Medan, who provided invaluable support in data collection, fidelity monitoring, and assessment administration. This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Acknowledgements

The authors declare no conflict of interest. The study sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

REFERENCES

Araújo, D., & Davids, K. (2016). Team Synergies in Sport: Theory and Measures. *Frontiers in Psychology*, *7*, 1449–1449. https://doi.org/10.3389/fpsyg.2016.01449

Bankosz, Z., & Winiarski, S. (2018). The kinematics of forehand and backhand loop in table tennis and their association with skill level. *International Journal of Sports Science and Coaching*, *13*(1), 111–120. https://doi.org/10.1177/1747954117718047

Bańkosz, Z., & Winiarski, S. (2018). Correlations between Angular Velocities in Selected Joints and Velocity of Table Tennis Racket during Topspin Forehand and Backhand. *PubMed*, *17*(2), 330–338. https://pubmed.ncbi.nlm.nih.gov/29769835

Bernstein, N. A. (1967). *The coordination and regulation of movements*. Pergamon Press.

Broadbent, D. P., Causer, J., Williams, A. M., & Ford, P. R. (2014). Perceptual-cognitive skill training and its transfer to expert performance in the field: Future research directions. *Brunel University Research Archive (BURA) (Brunel University London)*, *15*(4), 322–331. https://doi.org/10.1080/17461391.2014.957727

Buszard, T., Garofolini, A., Reid, M., Farrow, D., Oppici, L., & Whiteside, D. (2020). Scaling sports equipment for children promotes functional movement variability. *Scientific Reports*, *10*(1), 3111–3111. https://doi.org/10.1038/s41598-020-59475-5

Chen, W., & Jia, Y. (2025). Kinetic Chain Analysis of Tennis Stroke Motion Utilizing Wearable Sensors. *IEEE Transactions on Instrumentation and Measurement*, *74*, 1–8. https://doi.org/10.1109/tim.2025.3554882

Chow, J. Y., Davids, K., Button, C., & Renshaw, I. (2015). *Nonlinear Pedagogy in Skill Acquisition*. https://doi.org/10.4324/9781315813042

Djokic, Z., & Munivrana, G. (2021). Structure of technical and tactical knowledge as a determinant of performance in table tennis. *Acta Kinesiologica*, *15*(1), 1–9. https://doi.org/10.51371/issn.1840-2976.2021.15.1.1

Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, *41*(4), 1149–1160. https://doi.org/10.3758/brm.41.4.1149

Federation, I. T. T. (2023). *ITTF annual report 2023*. ITTF. https://www.ittf.com/annual-report

Fu, F. H., Nie, X. Y., & Wang, L. (2018). Effects of footwork training on stroke accuracy and game performance in junior table tennis players: A randomized controlled study. *Journal of Sports Sciences*, *36*(21), 2474–2481. https://doi.org/10.1080/02640414.2018.1449089

Fuchs, M., Liu, R., Lanzoni, I. M., Munivrana, G., Straub, G., Tamaki, S., Yoshida, K., Zhang, H., & Lames, M. (2018). Table tennis match analysis: a review. *Journal of Sports Sciences*, *36*(23), 2653–2662. https://doi.org/10.1080/02640414.2018.1450073

Hacques, G., Komar, J., Dicks, M., & Seifert, L. (2020). Exploring to learn and learning to explore. *Psychological Research*, *85*(4), 1367–1379. https://doi.org/10.1007/s00426-020-01352-x

Hao, Z., Feng, X. Y., & Kawaguchi, T. (2014). Application of movement anticipation training in table tennis to improve technical skills. *International Journal of Table Tennis Sciences*, *8*, 39–44.

Iino, Y., & Kojima, T. (2009). Kinematics of table tennis topspin forehands: effects of performance level and ball spin. *Journal of Sports Sciences*, *27*(12), 1311–1321. https://doi.org/10.1080/02640410903264458

Kondrič, M., Zagatto, A. M., & Sekulić, D. (2013). The physiological demands of table tennis: a review. *PubMed*, *12*(3), 362–370. https://pubmed.ncbi.nlm.nih.gov/24149139

Król, P., Franek, A., Durmała, J., Błaszczak, E., Ficek, K., Król, B., Detko, E., Wnuk, B., Białek, L., & Taradaj, J. (2015). Focused and Radial Shock Wave Therapy in the Treatment of Tennis Elbow: A Pilot Randomised Controlled Study. *Journal of Human Kinetics*, *47*(1), 127–135. https://doi.org/10.1515/hukin-2015-0068

Lanzoni, I. M., Michele, R. D., & Merni, F. (2013). A notational analysis of shot characteristics in top-level table tennis players. *European Journal of Sport Science*, *14*(4), 309–317. https://doi.org/10.1080/17461391.2013.819382

Latash, M. L. (2012). The bliss (not the problem) of motor abundance (not redundancy). *Experimental Brain Research*, *217*(1), 1–5. https://doi.org/10.1007/s00221-012-3000-4

Lee, M., Chow, J. Y., Komar, J., Tan, C. W. K., & Button, C. (2014). Nonlinear Pedagogy: An Effective Approach to Cater for Individual Differences in Learning a Sports Skill. *PLoS ONE*, *9*(8). https://doi.org/10.1371/journal.pone.0104744

Mahardika, F., Alim, A., Nurfadhila, R., & Yulianto, W. D. (2022). Comparison Of Open And Closed Stance Forehand Strokes Among Yogyakarta Junior Tennis Players. *European Journal of Physical Education and Sport Science*, *8*(6). https://doi.org/10.46827/ejpe.v8i6.4448

Munivrana, G., Petrinović, L., & Kondrič, M. (2015). Structural Analysis of Technical-Tactical Elements in Table Tennis and their Role in Different Playing Zones. *Journal of Human Kinetics*, *47*(1), 197–214. https://doi.org/10.1515/hukin-2015-0076

Pill, S. (2018). Game sense coaching: Practitioner experiences, challenges and thoughts on implementation. *Sports Coaching Review*, *7*(2), 147–161. https://doi.org/10.1080/21640629.2017.1349216

Prasetyo, S., & Sari, Z. N. (2025). Implementation of the Kurikulum Merdeka in high school physical education. *Inovasi Kurikulum*, *22*(1), 449–464. https://doi.org/10.17509/jik.v22i1.80053

Puspitasari, N., Sugiyanto, F. X., & Kristiyanto, A. (2021). Developing a table tennis forehand drive accuracy test instrument for junior high school students. *Journal of Physical Education and Sport*, *21*(3), 1542–1549. https://doi.org/10.7752/jpes.2021.03194

Qian, J., Zhang, Y., Baker, J. S., & Gu, Y. (2016). Effects of performance level on lower limb kinematics during table tennis forehand loop. *PubMed*, *18*(3), 149–155. https://pubmed.ncbi.nlm.nih.gov/27840437

Renshaw, I., Davids, K., Newcombe, D., & Roberts, W. (2019). *The Constraints-Led Approach*. https://doi.org/10.4324/9781315102351

Roberts, W., Newcombe, D., & Davids, K. (2018). Application of a Constraints-Led Approach to pedagogy in schools: embarking on a journey to nurture Physical Literacy in primary physical education. *Physical Education and Sport Pedagogy*, *24*(2), 162–175. https://doi.org/10.1080/17408989.2018.1552675

Schulz, K. F., Altman, D. G., Moher, D., & Group, for the C. (2010). CONSORT 2010 Statement: Updated Guidelines for Reporting Parallel Group Randomised Trials. *PLoS Medicine*, *7*(3). https://doi.org/10.1371/journal.pmed.1000251

Tang, J., Chen, X., & Wang, H. (2026). Effects of the sport education model on table tennis skills, sport motivation, and social adaptation in high school students. *Frontiers in Psychology*, *17*, 1756123–1756123. https://doi.org/10.3389/fpsyg.2026.1756123

Warren, W. H. (2006). The dynamics of perception and action. *Psychological Review*, *113*(2), 358–389. https://doi.org/10.1037/0033-295x.113.2.358

Widiastuti. (2019). *Tes dan pengukuran olahraga [Sport testing and measurement]*. Rajawali Pers.

World Medical Association Declaration of Helsinki. (2013). *JAMA*, *310*(20), 2191–2191. https://doi.org/10.1001/jama.2013.281053

Zagatto, A. M., Morel, E. A., & Gobatto, C. A. (2016). Physiological responses and match characteristics in official table tennis competitions. *Journal of Sports Sciences*, *34*(7), 648–654. https://doi.org/10.1080/02640414.2015.1069384

Zayas, M. Á. O., Linares, A. J. C., Lecina, M., Ochiană, N., García-Giménez, A., & Fuente, F. P. de la. (2025). Table Tennis as a Tool for Physical Education and Health Promotion in Primary Schools: A Systematic Review. *Sports*, *13*(8), 251–251. https://doi.org/10.3390/sports13080251

Zeng, H. Z., Leung, R. W., & Mclntyre, S. P. (2019). Skill development and game performance improvements of table tennis for physical education students. *Journal of Physical Education and Sport*, *19*(4), 2393–2399. https://doi.org/10.7752/jpes.2019.04360