Effects of combined physical and game simulation training on motor skills and backhand smash stability in adolescent table tennis players

Efectos del entrenamiento combinado físico y de simulación de juego sobre las habilidades motrices y la estabilidad del remate de revés en jugadores adolescentes de tenis de mesa

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Abstract

Introduction: Motor skills and performance stability are critical for successful backhand smash execution in table tennis. However, evidence on the combined effects of physical conditioning and game-based simulation training on these outcomes in adolescent players remains limited.
Objective: This study aimed to examine the effects of a combined physical and game simulation training program on motor skills, backhand smash performance, and stroke stability in adolescent table tennis players.
Methodology: A quasi-experimental pretest–posttest control group design was used. Sixty adolescent players (aged 13–17 years) from three clubs in Makassar were randomly assigned to an experimental group (n = 30) and a control group (n = 30). The experimental group received combined physical and game simulation training, while the control group followed conventional technique-based training. The intervention lasted eight weeks with three sessions per week. Motor skills were assessed using a table tennis skill test, and stroke stability was evaluated through video-based motion analysis. Data were analyzed using paired t-tests and MANOVA ($p < 0.05$).
Results: The experimental group showed significantly greater improvements in motor skills ($\Delta = 13.8$, $p < 0.001$) and backhand smash stability ($\Delta = 0.13$, $p < 0.001$). Multivariate analysis revealed a significant overall effect ($p = 0.001$), with large effect sizes for motor skills ($\eta^2 = 0.41$) and moderate-to-large effects for stability ($\eta^2 = 0.33$).
Conclusion: These findings show that combined physical and game-simulation training is more effective than conventional methods in improving motor skills, backhand smash performance, and stroke stability.

Keywords

Adolescent athletes; game simulation; motor performance; stroke accuracy; technical consistency.

Resumen

Introducción: Las habilidades motrices y la estabilidad del rendimiento son esenciales para el éxito en el tenis de mesa, especialmente en la ejecución del remate de revés, que requiere consistencia en el movimiento, precisión en el golpe y adaptabilidad. Sin embargo, pocos estudios han examinado los efectos combinados del acondicionamiento físico y el entrenamiento de simulación basado en juegos sobre las habilidades motrices y la estabilidad del remate de revés en jugadores adolescentes.
Objetivo: Este estudio tuvo como objetivo examinar los efectos de un programa combinado de entrenamiento físico y simulación de juego sobre las habilidades motoras, el rendimiento del remate de revés y la estabilidad del golpe en jugadores adolescentes de tenis de mesa.
Metodología: Se utilizó un diseño cuasiexperimental con grupo control y medidas pretest–postest. Participaron 60 jugadores adolescentes (13–17 años) de tres clubes en Makassar, asignados aleatoriamente a un grupo experimental (n = 30) y un grupo control (n = 30). La intervención tuvo una duración de ocho semanas con tres sesiones por semana. Las habilidades motrices se evaluaron mediante una prueba específica, mientras que la estabilidad del golpe se analizó mediante un sistema de análisis de movimiento basado en video. Los datos se analizaron mediante pruebas t pareadas y MANOVA ($p < 0.05$).
Resultados: El grupo experimental mostró mejoras significativamente mayores en habilidades motrices ($\Delta = 13.8$, $p < 0.001$) y estabilidad del remate de revés ($\Delta = 0.13$, $p < 0.001$). El análisis multivariado indicó un efecto significativo ($p = 0.001$), con tamaños del efecto grandes ($\eta^2 = 0.41$) y moderados-altos ($\eta^2 = 0.33$).
Conclusión: Estos hallazgos demuestran que el entrenamiento físico combinado con la simulación de juegos es más eficaz que los métodos convencionales para mejorar las habilidades motoras, el rendimiento del remate de revés y la estabilidad del golpe en jugadores adolescentes de tenis de mesa.

Palabras clave

Atletas adolescentes; simulación de juego; rendimiento motor; precisión en el golpeo; consistencia técnica.

Introduction

Table tennis is a racket sport that demands a combination of physical, technical, and cognitive abilities within a very fast tempo (Ding et al., 2024; Ren et al., 2025). The dynamic nature of the game requires athletes to be able to respond quickly and precisely to various changes in the match situation. In each rally, athletes are required to process visual information, predict the direction of the ball, and execute movements with precise coordination in a very short time (Hodges et al., 2021; Thieschäfer & Büsch, 2022). Therefore, a table tennis athlete's performance is greatly influenced by the quality of their motor skills, neuromuscular coordination, and movement stability during playing techniques.

Motor skills are fundamental abilities that enable individuals to control body movements effectively and efficiently in various physical activity situations (Jariono et al., 2024; Plakias & Karakitsiou, 2024). In the context of table tennis, motor skills play a crucial role in supporting coordination between arm and leg movements, as well as body positioning during strokes. This ability enables athletes to maintain body balance, adjust their position to the direction of the incoming ball, and deliver accurate and consistent strokes (Ferrández et al., 2021). Stability of technical performance is a crucial factor because movement consistency will determine the quality of strokes delivered during a match (Gan et al., 2025; Nian et al., 2025).

One of the key attacking techniques in table tennis is the backhand smash, which requires a high level of coordination between strength, timing, and movement control. Although less frequently used, the backhand smash remains a critical offensive technique in specific match situations, particularly when responding to high balls or finishing attacking rallies. Inconsistent movement patterns during execution can reduce shot accuracy, power, and overall effectiveness in competitive situations. Therefore, the development of both motor skills and movement stability is essential for optimizing this technique, particularly during the developmental stage of adolescent athletes.

In sports coaching practice, conventional technique training methods are still widely used to improve athletes' skills. This approach generally focuses on repeating technical movements over and over again with the goal of building consistency in movement patterns (Jahanian-Najafabadi & Davoodi, 2025; Ren et al., 2025). While this method is effective in strengthening mastery of basic techniques, approaches that emphasize only repetition often fail to develop athletes' adaptability to the dynamics of real-world play (Cassidy et al., 2023). This limitation highlights a critical gap between controlled technical training and the demands of actual-game performance. Furthermore, performance characteristics differ between male and female players, with males tending to adopt more offensive playing styles characterized by greater use of forehand, backhand, and flip techniques, whereas females generally demonstrate more defensive tactical patterns (de la Fuente et al., 2023).

Developments in sports coaching science indicate that training programs that integrate various training components can have a more optimal impact on improving athlete performance. Physical training that encompasses strength, balance, and coordination can improve neuromuscular capacity, supporting the quality of technical execution in sports (Zemková & Zapletalová, 2022). Increased muscle strength and body stability enable athletes to produce more powerful and controlled shots, while improved coordination helps athletes adapt movements quickly to changing game situations.

In addition to physical training, game simulation-based training approaches are increasingly being used in modern sports training programs. Game simulations allow athletes to train in situations that mimic actual match conditions. Through this approach, athletes not only practice technical skills but also develop perception, decision-making, and tactical awareness in the game. Training designed to replicate match contexts is believed to improve motor adaptability and performance consistency in competitive situations (Roumeliotis et al., 2025; Wu et al., 2024). These approaches reflect contemporary perspectives in motor learning, particularly ecological dynamics, which emphasize adaptive skill development through interaction between the individual, task, and environment.

Despite these advances, existing research has largely examined physical training and game-based simulation as separate approaches, with a primary focus on general performance indicators such as technical accuracy or physical capacity. Critically, there is a lack of experimental studies investigating the integrated effects of neuromuscular physical training and game simulation on the stability of specific stroke techniques in racket sports. This gap is particularly evident in adolescent table tennis players,

where stroke stability represents a fundamental yet underexplored component of performance development. Furthermore, previous studies have rarely examined how integrated training influences both motor skill development and movement consistency within a single experimental framework.

Therefore, this study aims to examine the effects of a combined physical and game simulation training program on motor skills and backhand smash stability in adolescent table tennis players. By focusing on stroke stability as a specific performance outcome and integrating both physical and contextual training components, this study provides a more targeted and comprehensive approach to training research in youth racket sports.

Based on the theoretical framework of motor learning and ecological dynamics, it is hypothesized that athletes who undergo combined physical and game simulation training will demonstrate greater improvements in motor skills and backhand smash stability compared to those who follow conventional technique-based training.

Method

Study Design

This study employed a quantitative approach using a quasi-experimental pretest–posttest control group design. This design was selected to examine causal effects of a combined physical and game simulation training program on motor skills and backhand smash stability, while allowing comparison with a control group under actual training conditions. The study was conducted at several table tennis clubs in Makassar City over eight weeks, with a training frequency of three sessions per week.

This study adhered to ethical standards for research involving human participants. All participants and their parents or guardians provided written informed consent prior to participation. The study protocol was conducted in accordance with the Declaration of Helsinki. This study received ethical approval from the Research Ethics Committee of Universitas Negeri Makassar on April 9, 2025 (Approval No. 2041/UN.36.11/TU//2025).

Participants

A total of 60 adolescent table tennis athletes (aged 13-17 years) were recruited from three clubs in Makassar City. Participants had at least two years of competitive training experience and regularly participated in regional competitions. All participants were right-handed and categorized as intermediate level players. In general, the athletes employed an offensive playing style dominated by forehand and backhand topspin and smash strokes. In terms of equipment, all participants used standard wooden blade rackets with ITTF-approved inverted rubber (sponge thickness 1.8–2.1 mm), and none used defensive rubber such as long-pips or anti-spin. Inclusion criteria included: (1) actively participating in club training, (2) no injuries during the study, and (3) willingness to participate in all intervention sessions. Participants were randomly assigned to either the experimental group or the control group.

Table 1. Participant Characteristics

Variable	Value
Total participants	60 athletes
Age (years)	13–17
Sex	36 males, 24 females
Handedness	100% right-handed
Playing level	Intermediate (regional level)
Training experience	≥ 2 years
Height (cm)	162.4 ± 7.8
Body mass (kg)	54.6 ± 8.5
Playing style	Predominantly offensive
Rubber type	Inverted (ITTF-approved)
Sponge thickness	1.8–2.1 mm
Defensive rubber use	Not used

Procedure

The study consisted of three phases: pre-test, intervention, and post-test. In the pre-test phase, all participants were assessed for motor skills and backhand smash stability.

The intervention lasted eight weeks, with three sessions per week (90 minutes per session). The physical training component consisted of exercises targeting lower-body strength, core stability, balance, agility, and coordination. The program consisted of ladder drills, multi-directional agility drills, balance board exercises, medicine ball rotational throws, and plyometric exercises, performed in 3-4 sets of 8-12 repetitions with 60–90 seconds rest intervals.

The experimental group performed a combined training program integrating physical training with game simulation. Game simulations included structured rally drills, variable ball placement, pressure-based scoring scenarios, and decision-making drills requiring rapid stroke selection. These activities were designed to enhance perception–action coupling and movement adaptability under dynamic conditions.

The control group followed conventional technique training focused on repetitive drills (forehand, backhand, serve, and footwork). Both groups trained under similar environmental conditions and coaching supervision to minimize external bias.

Instruments

Two primary instruments were used:

Motor Skills Test

Motor skills were assessed using a table tennis-specific skill test evaluating coordination, control, balance, and shot accuracy. The test protocol was adapted from standardized table tennis skill assessment procedures (Faber et al., 2021). The instrument demonstrated acceptable reliability (Cronbach's α = 0.87). Coordination is defined as the ability to synchronize the movements of the upper and lower limbs during the execution of a shot, particularly in response to variations in the direction and speed of the ball. Control refers to an athlete's ability to regulate the force, timing, and precision of movements to produce consistent technical execution. Balance is assessed as the ability to maintain postural stability during dynamic movements, particularly when transitioning between shots and adjusting body position. Shot accuracy is measured by accurately placing the ball in a predetermined target area on the table through repeated trials.

Backhand Smash Stability

Backhand smash performance was assessed using video-based motion analysis. Movements were recorded using a high-definition camera positioned laterally (sagittal plane) at a distance of 3 meters and a height of 1.2 meters. As all participants were right-handed, camera placement was standardized on the dominant side. The analysis focused on kinematic variables, particularly joint coordination of the wrist, elbow, and shoulder, identified using standardized anatomical landmarks. Stroke stability was defined as the consistency of movement execution across repeated trials, quantified through variability scores. Video recordings were analyzed on a frame-by-frame basis to evaluate trajectory, consistency, and accuracy. Trajectory referred to the movement path of the racket and ball, consistency to intra-individual variability across trials, and accuracy to ball placement on predefined target areas. A structured observation sheet combining quantitative and qualitative assessments was used. Two independent evaluators with expertise in table tennis performance conducted the analysis. A calibration session was performed prior to assessment, and inter-rater reliability showed excellent agreement (ICC = 0.91).

Physical Activity Monitoring

A validated physical activity questionnaire, adapted from the International Physical Activity Questionnaire Short Form (IPAQ-SF), was used to monitor participants' training adherence and additional physical activities. The instrument has demonstrated acceptable validity and reliability in adolescent populations. This measure was included to control for external training influences during the intervention period, and the results were used as a covariate in the data analysis.

Data Analysis

Data were analyzed using IBM SPSS Statistics version 25 (IBM Corp., Armonk, NY, USA). Descriptive statistics (mean ± standard deviation) were calculated for all variables. Prior to inferential analysis, data normality was assessed using the Shapiro–Wilk test, and homogeneity of variance was tested using Levene's test. Paired t-tests were used to examine within-group differences (pre–post), while MANOVA was performed to analyze differences between groups with a significance level of $p < 0.05$. Effect sizes were calculated using Cohen's d and partial eta squared (η^2), and interpreted as small (0.01), medium (0.06), and large (≥0.14).

Results

After the eight-week intervention, the experimental group demonstrated significantly higher post-test scores in motor skills and backhand smash stability compared with the control group. Descriptive analysis revealed an increase in the average scores for both study variables in both the experimental and control groups, but the increase was greater in the experimental group than in the control group.

Table 2 presents a comparison of the average scores and standard deviations between the pre-test and post-test results in the experimental and control groups.

Table 2. Changes in Motor Skill Scores Following the Eight-Week Intervention

Variable	Group	Pre-test (Mean ± SD)	Post-test (Mean ± SD)	Δ Mean	p-value
Motor skills	Experimental	73.4 ± 5.6	87.2 ± 4.9	+13.8	< 0.001*
Motor skills	Control	74.1 ± 5.8	79.3 ± 5.5	+5.2	0.041*

Significant differences, $p < 0.05$

Table 2 shows that both groups experienced improvements in motor skills after the eight-week intervention. The experimental group demonstrated an increase in mean scores from 73.4 ± 5.6 at pre-test to 87.2 ± 4.9 at post-test, with a mean improvement of 13.8 points, which was statistically significant ($p < 0.001$). Similarly, the control group showed an increase from 74.1 ± 5.8 to 79.3 ± 5.5, with a mean improvement of 5.2 points ($p = 0.041$). However, the increase in motor skill scores was greater in the experimental group compared with the control group.

Table 3. Pre-test and Post-test Results of Backhand Smash Stability

Variable	Group	Pre-test (Mean ± SD)	Post-test (Mean ± SD)	Δ Mean	p-value
Backhand Smash Stability	Experimental	0.80 ± 0.07	0.93 ± 0.05	+0.13	< 0.001*
Backhand Smash Stability	Control	0.81 ± 0.06	0.86 ± 0.06	+0.05	0.064

*Significant difference at $p < 0.05$

Table 3 presents the pre-test and post-test results of backhand smash stability in both groups after the eight-week intervention. The experimental group showed an increase in stability scores from 0.80 ± 0.07 at pre-test to 0.93 ± 0.05 at post-test, with a mean improvement of 0.13 and a statistically significant difference ($p < 0.001$). In contrast, the control group demonstrated a smaller increase from 0.81 ± 0.06 to 0.86 ± 0.06, with a mean improvement of 0.05, which was not statistically significant ($p = 0.064$). These results indicate that the experimental group achieved greater improvements in backhand smash stability compared with the control group.

Figure 1. Changes in Motor Skills Scores Between Experimental and Control Groups from Pre-test to Post-test

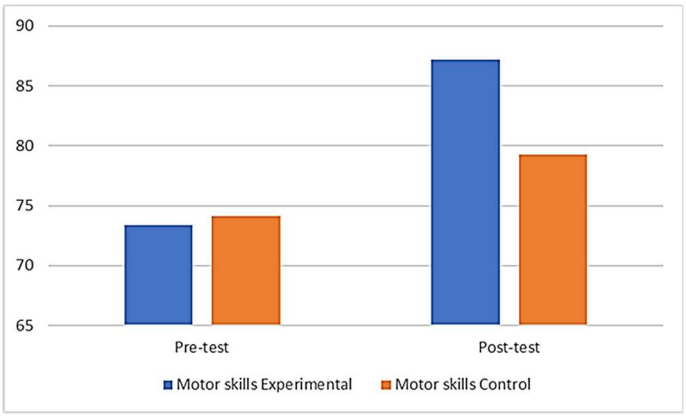
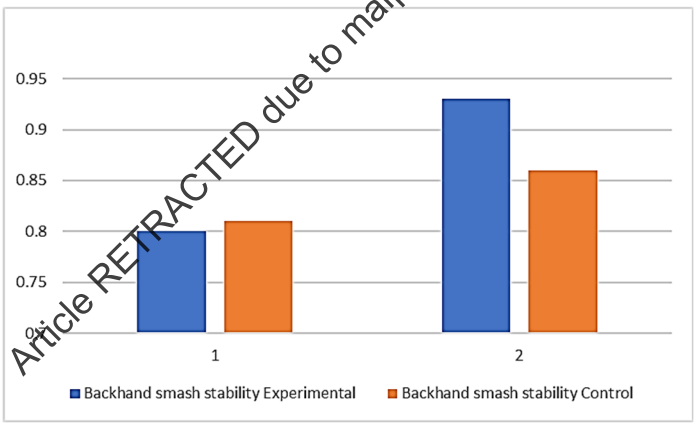


Figure 2. Changes in Backhand Smash Stability from Pre-Test to Post-Test in the Experimental and Control Groups



To determine the differences in the effects of the experimental and control groups simultaneously on both research variables, a multivariate analysis of variance (MANOVA) was performed. The analysis revealed a significant difference between the two groups (Wilks' Lambda = 0.741, F(2,57) = 7.94, p = 0.001). These results indicate that the training program significantly impacted motor skills and backhand smash performance stability.

Further analysis using univariate tests showed that the combined training program significantly impacted motor skills (F = 15.27, p = 0.000) and backhand smash performance stability (F = 10.84, p = 0.002).

To determine the magnitude of the training program's influence on the research variables, effect size analysis was performed using Cohen's d and Partial Eta Squared (η^2). The analysis results showed that the combined training program had a significant impact on improving motor skills (Partial η^2 = 0.41) and stability of backhand smash performance (Partial η^2 = 0.33). The effect size analysis indicated a large effect of the intervention on motor skills and a moderate-to-large effect on backhand smash stability, suggesting that the combined training program had a substantial impact on performance improvements.

As shown in Figure 1 and Figure 2, the experimental group demonstrated higher post-test scores in motor skills and backhand smash stability compared with the control group. Statistically significant differences are indicated by an asterisk (*) in the figures. In addition, no significant differences in external physical activity levels were observed between the two groups during the intervention period.

Discussion

This study aimed to examine the effects of a combined physical and game simulation training program on motor skills and backhand smash stability in adolescent table tennis players. The findings indicate that the combined training program was more effective than conventional technique-based training in improving both motor skills and backhand smash stability. However, these findings should be interpreted with caution due to several limitations, including the relatively small sample size and the absence of detailed technical measurements related to equipment and biomechanical variables.

The results of the study showed that a training program combining physical training and game simulation significantly improved motor skills and stability in backhand smash performance in adolescent table tennis athletes. The greater improvement observed in the experimental group compared with the control group indicates that a training approach integrating physical components and game simulation is more effective in improving technical performance than conventional training methods that focus solely on technique repetition. This finding aligns with previous research indicating that integrated training approaches can improve stroke-specific performance and movement consistency in racket sports, particularly in the execution of technically demanding skills (Faber et al., 2021; Kong & M.S., 2024). In addition, drill-based training significantly improves forehand and backhand stroke skills in racket athletes, indicating that practicing repetitive techniques contributes to increased movement consistency (Maulana et al., 2025).

It is also important to note that the control group showed a significant improvement in motor skills. This improvement may be attributed to the effects of repeated technical practice, which can enhance basic movement consistency and skill acquisition, as supported by motor learning theory emphasizing repetition-based adaptation (Faber et al., 2021).

The observed improvement in motor skills may be attributed to neuromuscular adaptations induced by the physical training component of the intervention. Training involving strength, balance, coordination, and agility helps improve movement control and muscle efficiency during technical execution. Neuromuscular adaptations that occur during training enable athletes to produce more stable and accurate movements. In table tennis, which has a fast tempo, coordination between the nervous system and the muscular system is crucial for the quality of shot execution (Santos et al., 2023; Zemková, 2022).

These findings are consistent with previous studies indicating that integrated training approaches can enhance perception-action coupling and movement efficiency in racket sports (Behrendt et al., 2021; Cassidy et al., 2023), although the present study did not directly measure neuromuscular or perceptual mechanisms, and thus interpretations should be considered cautiously.

In addition to improving physical capacity, the use of game simulation in training programs also contributes significantly to improving athletes' performance stability. Game simulation allows athletes to train in conditions that mimic real-life match situations. This approach not only trains technical skills but also develops athletes' perception, decision-making, and tactical response abilities in dealing with varying game situations (Jia et al., 2024; Wang et al., 2025).

The training approach used in this study aligns with the concept of ecological dynamics, which views sports skills as the result of interactions between the individual, the task, and the training environment. From this perspective, motor learning occurs not only through repetition of the same movement but also through exploration of various movement variations under different conditions (Gan et al., 2025; Roumeliotis et al., 2025).

Specifically, the improvement in backhand smash stability observed in the experimental group suggests that training integrating physical conditioning and game simulation may enhance the consistency of stroke execution under dynamic conditions. However, this interpretation is based on performance outcomes rather than direct biomechanical or neurophysiological measurements. Unlike general performance improvements, the present findings specifically highlight the importance of training design in enhancing backhand smash stability, which is a complex technique requiring coordination, timing, and movement consistency. This supports the need for technique-specific and context-based training approaches in table tennis.

Although this study showed positive results, there are several limitations that should be considered. This study involved a limited sample size and was limited to table tennis clubs in Makassar City, so generalizing the results to a broader population of athletes requires caution. Furthermore, the eight-week training program did not allow for evaluation of the long-term impact of the training program on athlete performance development.

Future studies should employ larger samples, longitudinal designs, and incorporate detailed biomechanical and physiological measurements to better understand the mechanisms underlying improvements in backhand smash performance. In addition, references in this section should follow the journal citation format consistently rather than using numerical placeholders.

Importantly, the present findings specifically emphasize improvements in backhand smash stability, rather than general performance, highlighting the importance of technique-specific training interventions in table tennis.

Conclusions

This study demonstrated that a training program integrating physical conditioning and game simulation resulted in greater improvements in motor skills and backhand smash stability in adolescent table tennis athletes compared to conventional technique-based training. These findings suggest that integrating physical conditioning with game-based simulation may enhance movement consistency and technical stability during backhand smash execution. However, interpretation of the underlying mechanisms should be approached with caution, as this study did not directly assess neuromuscular or biomechanical variables.

From a practical perspective, the results suggest that a training program combining physical components and game simulation may provide a more effective approach to improving technique-specific performance, particularly backhand smash stability, in adolescent table tennis athletes.

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