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Training method and arm strength interactions in novice table tennis skill development: A factorial study

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ABSTRACT

Background: Developing proficiency in the backhand drive is essential for novice table tennis players, yet identifying the most effective training methodologies remains a significant challenge. However, existing literature has predominantly examined training methods in isolation. There is a notable lack of empirical evidence regarding how these methods interact with individual physical attributes, leading to a potential gap in understanding effective personalized coaching strategies. **Objectives**: This study aimed to examine the interaction between two common training methods (wall bounce vs. pairing) and arm muscle strength (strong vs. weak) on the acquisition of backhand drive skills in novice players. **Methods**: A 2 × 2 factorial experimental design was employed over an eight-week period with 76 novice male university students (age 18-22). Participants were stratified into four groups based on the training method and arm muscle strength, which was assessed using a 30-second push-up test. Backhand drive ability was evaluated using a validated scoring rubric. **Finding/Results**: A two-way ANOVA revealed a significant main effects for training method ($p < .043$, $\eta p^2 = 0.11$) and arm muscle strength ($p < .001$, $\eta p^2 = 0.70$), as well as an interaction effect between these factors on backhand drive performance ($F(1.36) = 6.99$, $p < .05$, $\eta p^2 = 0.16$). Post-hoc analysis showed that the wall bounce method was significantly more effective for players with strong arm muscles ($p < .05$), whereas for players with weaker arm muscles, no significant difference was found between the two training methods ($p > .05$). **Conclusion**: The optimal training method for backhand drive development is contingent on the athlete's physical characteristics. This finding challenges the one-size-fits-all coaching paradigm and provides strong evidence for a personalized approach that matches training methodologies to the individual strength levels of athletes.

Keywords: Table tennis; skill acquisition; aptitude-treatment interaction; motor learning; arm muscle strength

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INTRODUCTION

Table tennis is a complex, high-velocity sport that demands mastery of fundamental techniques, among which the backhand drive is a critical skill for competitive success. The ability to execute a powerful and consistent backhand drive significantly influences the shot quality, tactical options, and overall outcome of a match (Fuchs et al., 2018). A proficient backhand drive requires precise coordination of stroke mechanics and body position. However, the ultimate generation of racket speed and shot power is rooted in an athlete's physical capacity (Zhang et al., 2018). From a biomechanical standpoint, this power originates from a rapid kinetic chain involving explosive contractions that travel from the shoulder to the forearm and wrist muscles (Iino & Kojima, 2016). Consequently, an athlete's physical attributes, particularly arm muscle strength, are crucial determinants of performance quality and key factors in developing high-level proficiency (Guo et al., 2019; Zhang et al., 2018).

The process of acquiring a complex motor skill, such as the backhand drive, is not uniform across all individuals. According to Fitts and Posner's classic three-stage model, learners progress through cognitive, associative, and autonomous phases, with individual differences in physical and cognitive attributes heavily influencing the rate and quality of this progression (Kee, 2019). This variability highlights an important principle in educational psychology and motor learning, namely the Aptitude–Treatment Interaction (ATI). The ATI perspective suggests that learning outcomes are maximized when instructional methods "treatment" are aligned with the learner's individual characteristics and abilities "aptitude" (Pang, 2018). Within the scope of this study, arm muscle strength is considered a key aptitude. Because physical strength can influence an athlete's response to a training method, a uniform or standardized coaching strategy may not produce optimal results.

Within this ATI framework, arm muscle strength serves as the critical 'aptitude' (Guo et al., 2019; Ninglan et al., 2019). As established earlier, strength acts as the biomechanical foundation for shot power and control (Zhang & Huang, 2023). However, Kolman et al. (2019) argued that enhancing backhand drive skills does not rely solely on physical strength but also on effective training methods tailored to players' characteristics, especially beginners.

In novice table tennis instruction, the two widely employed methods are wall bounce and pairing methods (Langitan, 2018). Each has its distinct pedagogical philosophy. As noted by Ganieva et al. (2024) and Santosa et al. (2017) the wall bounce method allows athletes to practice repeatedly against a wall, ensuring a predictable return and making large volumes of practice possible without a training partner. Such a setting reflects the concept of deliberate practice, which highlights the importance of structured, high-frequency training for the refinement and automation of motor skills (Ericsson & Harwell, 2019).

Although the value of individualized instruction is widely recognized, much of the existing research has examined training methods separately, without considering how these methods interact with learner characteristics (Kamalussadad et al., 2022; Michalski et al., 2019). This creates a critical gap in the literature: the failure to empirically test how training modes interact with an athlete's physical attributes. Furthermore, while the practical constraints of coaching in educational and community settings, such as limited facilities and equipment, are well documented (Dewi et al., 2021), there is a lack of evidence regarding which resource-efficient methods yield the best return on investment for specific athlete profiles.

To address these issues, the primary scientific contribution of this study is the empirical application of the Aptitude-Treatment Interaction (ATI) model to table tennis skill acquisition. Specifically, this research distinguishes itself from previous work by moving beyond the comparison of 'which method is best' to answer 'which method is best for whom.' By examining the interaction between training mode (wall bounce vs. pairing) and physical aptitude (arm strength), this study aims to provide a validated, evidence-based framework for personalized coaching.

METHOD

This section outlines the procedures used in the experiment, with an emphasis on maintaining rigorness of the study (consistency and accuracy) and ensuring that it could be replicated. All steps followed a standardized protocol, and informed consent was obtained from every participant before the study began.

Participants and Ethical Approval

The study involved 76 male sports science students from Universitas Negeri Manado (UNIMA) aged 18-22 years (M = 20.4, SD = 1.6). Participants were selected based on the criteria that they were novice players (no formal club training) and free from upper-body injuries. A post-hoc power analysis indicated that the sample size of 76 was sufficient to detect a medium-to-large interaction effect ($\eta p^2 > 0.10$) with a statistical power of 0.80 at $\alpha = 0.05$. Prior to data collection, the study protocol was reviewed and approved by the Research Ethics Committee of Universitas Negeri Manado (Ref: 2951/UN41.3/TU/2023). All participants provided written informed consent.

Research Design

A 2 × 2 factorial experimental design was employed. The two independent variables were Training Method (Wall Bounce vs. Pairing) and Arm Muscle Strength (Strong vs. Weak). To establish the strength groups, participants were stratified based on their push-up test scores. Following the standard psychometric procedure for maximizing group differentiation established by Kelley (1939), the top 27% of performers were categorized as "Strong" and the bottom 27% as "Weak." Participants within these strata were then randomly assigned to either the Wall Bounce or Pairing group using a computer-generated random number sequence to ensure allocation concealment.

Instruments

Arm Muscle Strength: Upper body strength was assessed using a 30-second push-up test (Artanayasa et al., 2022). To ensure validity, the test followed a standardized protocol: participants performed maximum repetitions in 30 seconds, maintaining a straight body line. Only repetitions with full elbow extension and chest lowering were counted. Backhand Drive Ability: Performance was evaluated using a validated three-component scoring rubric assessing (1) Stance, (2) Stroke Execution, and (3) Follow-through. Three trained assessors (blinded to group allocation) evaluated the players, showing high inter-rater reliability ($\alpha = 0.89$).

Procedures and Treatment Fidelity

The intervention spanned eight weeks (3 sessions/week). Both groups followed the same volume: 4 sets of 40 repetitions/session. To ensure treatment fidelity, all training sessions were directly supervised by the lead researcher and two assistants. They monitored attendance and verified that participants adhered to the specific constraints of their assigned method (e.g., ensuring wall bounce distance was consistent or that pairs rotated roles correctly). The progression of intensity was standardized, moving from static strokes (Weeks 1-2) to dynamic targeting (Weeks 7-8), as detailed in **Table 1**.

Table 1. Summary of the Eight-Week Progressive Training Intervention

Week	Training Progression	Intensity (% Max Ability)
1-2	Backhand stroke practice (without ball)	60-70%
3-4	Backhand stroke with footwork (with ball)	60-70%
5-6	Directional backhand drives (cross-court and down-the-line)	80-90%
7-8	Targeted backhand drives (to specific zones)	80-90%

Data Analysis

Data were analyzed using SPSS version 23.0. The assumptions of normality were verified using the Shapiro-Wilk test (suitable for $n < 50$ per cell), and homogeneity of variance was confirmed using Levene's test ($p > .05$). A two-way ANOVA was conducted to examine the main effects and interaction between Training Method and Arm Muscle Strength. Effect sizes were calculated using partial eta-squared (ηp^2).

RESULTS AND DISCUSSION

Results

At the initial assessment, participants completed an average of 22.53 push-ups (SD = 5.45), indicating variation in strength levels within the group. The prerequisite tests confirmed that the data for all four experimental groups were normally distributed and had homogeneous variances, satisfying the assumptions for the two-way ANOVA.

ANOVA revealed a significant main effect for training method ($F(1.36) = 4.40$, $p = .043$, $\eta p^2 = 0.11$), with the wall bounce group ($M = 29.60$, $SD = 4.25$) outperforming the pairing group ($M = 28.45$, $SD = 2.86$). A highly significant main effect was also found for arm muscle strength ($F(1.36) = 84.99$, $p < .001$, $\eta p^2 = 0.70$), indicating that the strong-arm group performed substantially better than the weak-arm group, regardless of the training method.

Crucially, the analysis yielded a significant interaction effect between the training method and arm muscle strength (**Table 2**). This interaction ($F(1.36) = 6.99$, $p = .012$, $\eta p^2 = 0.16$) indicates that the effectiveness of the training methods was dependent on the participants' level of arm muscle strength.

Table 2. Two-Way ANOVA Results for Backhand Drive Ability

Source	df	SS	MS	F	p	ηp^2
Training Method (A)	1	17.225	17.225	4.40	.043	0.11
Arm Strength (B)	1	330.625	330.625	84.99	< .001	0.70
A × B Interaction	1	27.225	27.225	6.99	.012	0.16
Error	36	139.900	3.886			
Total	39	514.975				

The nature of this interaction is visualized in **Figure 1** and is detailed in **Table 3**. The crossed lines in the plot clearly illustrate the differential effects of the training methods on the two strength groups.

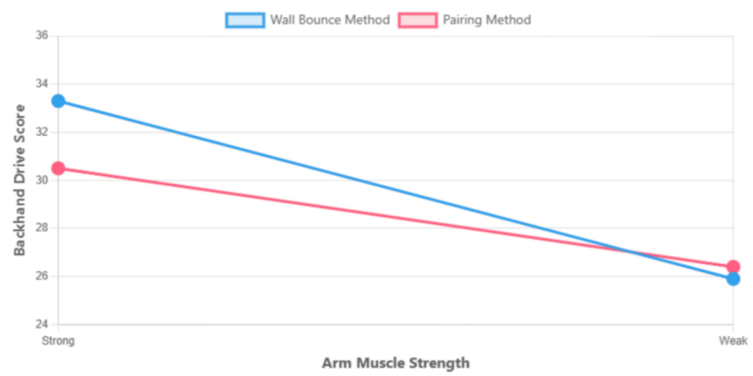

Figure 1. Interaction between Training Method and Arm Muscle Strength

Tukey's HSD post-hoc tests were conducted to decompose the interaction. For participants with strong arm muscles, the wall bounce method ($M=33.3$) was significantly more effective than the pairing method ($M = 30.5$) ($p < .05$). In contrast, for participants with weak arm muscles, there was no significant difference between the wall bounce method ($M = 25.9$) and the pairing method ($M = 26.4$) ($p > .05$).

Table 3. Post-Hoc Analysis of Backhand Drive Ability by Group

Group	Training Method	Arm Strength	M	SD	95% CI
A1	Wall Bounce	Strong	33.3	1.90	[32.0, 34.6]
A2	Wall Bounce	Weak	25.9	2.02	[24.4, 27.4]
B1	Pairing	Strong	30.5	1.90	[29.2, 31.8]
B2	Pairing	Weak	26.4	2.07	[24.9, 27.9]

Discussion

The primary contribution of this study is the empirical validation of the aptitude-treatment interaction in the context of sports skill acquisition. The significant interaction effect is the most important finding, as it moves beyond simply asking "which method is better?" to address the more nuanced question of "which method is better for whom?" (Pang, 2018). This idea is also supported by findings in other areas of motor learning. For example, a study on the long jump published in this journal showed an interaction between teaching methods and learners' motor educability (Zubaida et al., 2021). A similar pattern was observed in research on young tennis players, where game-based training proved more effective for younger athletes, while drill-based training worked better for older groups (Putri et al., 2024). Together, these results highlight the value of adopting a more individualized approach when coaching novice athletes.

The advantage of the wall bounce method for players with stronger arms can be explained through principles of motor learning and cognitive resource use. Because these athletes already had sufficient strength, they were less occupied with generating force and could focus more attention on refining their technique (Kantak & Winstein, 2012). The predictable, high-repetition nature of wall bounce practice provided a setting well suited to this type of deliberate practice. In such conditions, players were able to automate the backhand drive's kinetic chain and translate their physical strength into more consistent and accurate strokes (Schmidt et al., 2019).

For players with weaker arms, a "fatigue–technique trade-off" may have happened. The demanding, high-volume nature of wall bounce practice could have led to fatigue, which is known to reduce practice quality and hinder motor learning (Branscheidt et al., 2019). In contrast, the pairing method introduced pauses between strokes and a more interactive setting, which likely reduced fatigue. This lighter workload may also have supported motivation and engagement, helping these athletes maintain proper technique over a longer period. This aligns with research demonstrating that intrinsic motivation is a key factor in skill development and sustained engagement in physical activities (Wulf & Lewthwaite, 2016).

These findings have profound practical implications and support a paradigm shift in coaching practices. The traditional "one-size-fits-all" model, in which an entire group of novices is subjected to the same training regimen, appears to be suboptimal. This study advocates a new paradigm: Assess, then Prescribe. Coaches can use simple, practical field tests, such as the push-up test, to gain insight into an athlete's physical capacity. Based on this assessment, training can be personalized. Stronger athletes can be channeled into high-repetition, technique-focused drills, whereas athletes with developing strength may benefit more from interactive, game-based methods or a blended approach that prioritizes fatigue management and motivation.

Furthermore, this evidence-based personalized approach is remarkably resource-efficient. Both wall bounce and pairing methods are low-cost and highly accessible. These findings are particularly relevant for educational institutions and community sports programs that may lack extensive facilities or equipment (Dewi et al., 2021). This demonstrates that effective individualized skill development is achievable even in resource-constrained environments.

The results also underscore the fundamental importance of physical fitness. The large main effect of arm muscle strength reinforces the need to integrate dedicated strength and conditioning into table tennis training programs, even at the novice level (Xiong et al., 2022). For athletes with weaker arms, a concurrent strength development program is not only beneficial but also essential for unlocking their full potential. To this end, evidence from a meta-analysis suggests that circuit resistance training is a proven and effective strategy for maximizing the strength and power development needed for high-performance sports (Kahraman & Hocalar, 2024). Integrating such training would directly address the physical limitations observed in the weaker group, expanding their capacity to benefit from a wider range of skill-development drills in the future. This study's focus on the interaction between motor skill development and physical attributes contributes to the ongoing conversation within the Journal Sport Area regarding the multifaceted nature of physical education and motor learning (Juhanis et al., 2024; Zubaida et al., 2021).

Limitations and Future Directions

This study has several limitations that point to directions for future research. First, the intervention lasted only eight weeks, which may not be long enough to evaluate the lasting effects of skill development. Longer-term studies with follow-up or retention tests are needed to determine whether the learning outcomes observed here can be sustained over time. Second, the study sample was limited to male university students, which restricts the generalizability of the findings. Future research should include more diverse populations, including female athletes and players of different ages and initial skill levels, to enhance the external validity of the findings.

Third, a key limitation is the "specificity mismatch" in the strength assessment. Although the push-up test is a valid proxy for general upper-body strength, it does not directly measure the specific rotational power and wrist-forearm mechanics integral to the backhand drive. Future research should employ more sport-specific measures such as isokinetic dynamometry or handheld dynamometers. These measurements target wrist flexors and extensors to provide a more precise profile of an athlete's strength and its relationship with training outcomes. Finally, future research in ecological dynamics frameworks may explore non-linear pedagogy approaches that modulate constraints beyond physical strength.

CONCLUSION

The main aim of this study was to examine how training methods and arm muscle strength interact in shaping the backhand drive performance of novice table tennis players. The findings showed a clear interaction, indicating that the most effective training method depends on the athlete's physical capacity rather than a single universal approach. The key contribution of this research is the evidence it offers against a "one-size-fits-all" model of coaching. Instead, the results point to the value of tailoring training to individual needs. For example, stronger players appear to gain more from high-repetition drills that sharpen technique, while those still developing strength may progress better with interactive, game-based methods that limit fatigue and help sustain motivation. Overall, the study suggests a practical and resource-efficient framework that can guide coaches in designing adaptive programs to support the skill development of novice athletes.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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