



Development of a Specific Training Program to Improve Physical Fitness and Performance of Pickleball Athletes in Guangzhou Sports Polytechnic University

Shi Linjian¹ and Chanchai Siriphan²

Faculty of Sports Science and Technology, Bangkokthonburi University, Thailand

¹E-mail: tel872899987@gmail.com, ORCID ID: <https://orcid.org/0009-0003-9644-6305>

²E-mail: siriphan.cs@gmail.com, ORCID ID: <https://orcid.org/0009-0000-9981-655X>

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Abstract

Background and Aim: Although pickleball has rapidly gained popularity among Chinese university students, a significant issue remains the mismatch between current training methods and the sport's specific demands. At present, training still relies heavily on traditional approaches such as long-distance running or static strength exercises, which do not effectively target the development of agility, balance, reaction speed, and core strength that are essential for pickleball. As a result, despite students' high levels of interest, their skill progression remains slow. The main objective of this research was to develop a specific training program to improve the physical fitness and pickleball performance of athletes at Guangzhou Sports Polytechnic University.

Methodology: This research employed a mixed-method design to develop a specific training program to improve the physical fitness and pickleball performance of athletes. The population was 120 male pickleball athletes and 10 pickleball coaches on a pickleball team. The population was surveyed using questionnaires. The sample for the experiment was 30 athletes from the athletes' population using the purposive sampling method. All athletes were divided into two groups: an experimental group of 15 participants and a control group of 15 participants, using a systematic method. The experiment would last for a total of 8 weeks, 3 days a week, 1.5 hours a day. Research instruments included an in-depth interview with experts (IOC=0.90), a focus group outline, and the connoisseurship outline. For data analysis, independent sample t-tests were conducted to examine the difference between the experimental and control groups, while repeated measures ANOVA was employed to compare within-group differences across testing phases. Qualitative data from interviews, focus groups, and connoisseurship were analyzed through content analysis.

Results: 1) The experts confirmed that the training program is scientifically structured, practically feasible, and comprehensive, covering physical fitness, technical and tactical training, monitoring, recovery, and injury prevention. 2) The experimental group demonstrated highly significant superiority over the control group in all pickleball performance and physical fitness metrics post-intervention ($p < .05$). 3) Repeated measures ANOVA confirmed statistically significant overall improvements in all pickleball performance and physical fitness during the training period ($p < .05$).



Conclusion: The research results confirm that the structured, phased training program was effective in enhancing both technical-tactical performance and physical conditioning over the eight weeks. Therefore, it can be concluded that the experimental results are in accordance with the research hypothesis, with a significant difference at the 0.05 level.

Keywords: Specific Training Program; Pickleball Performance; Physical Fitness; Pickleball Athletes

Introduction

In recent years, pickleball has rapidly emerged as a popular sport in the global university sports arena due to its low entry barrier and high entertainment value. In the United States, the growth in pickleball participation has even surpassed that of traditional sports such as soccer, tennis, and basketball. The sport integrates technical and tactical elements from tennis, badminton, and table tennis, demanding that players develop agility, balance, reaction speed, and core strength. Its fitness, recreational, cultural, and competitive values align well with the developmental needs of China's current sports industry (Zhang et al., 2018). However, although some universities have started incorporating pickleball into their sports programs, the prevailing training system still relies predominantly on traditional methods such as long-distance running and static strength training, which lack the targeted and scientific approach required for pickleball. This mismatch has resulted in a common issue among students: high interest but slow skill improvement. A preliminary survey at Guangzhou Sports Polytechnic found that 68% of pickleball enthusiasts believe that the existing training methods "do not specifically improve game performance" (Guangzhou Sports Polytechnic University, 2023).

In recent years, the physical fitness of Chinese university students has been a growing concern, with studies indicating a decline in key indicators such as endurance, strength, and speed. Since 1985, national surveys have revealed a downward trend in these metrics among university students. For example, in 100-meter sprint tests, less than 10% of students achieve excellent results, and the excellence rate in strength tests is even lower. To address this issue, experts recommend enhancing health education, improving sports facilities, and fostering supportive exercise environments to effectively boost students' physical fitness and promote their holistic development.

At the same time, Functional Fitness Training, which enhances athletic performance and reduces injury risks by simulating sport-specific movement patterns, has been validated in traditional sports such as soccer and basketball (Cook et al., 2006). The core advantages of Functional Fitness Training lie in its movement integration, for example, using multi-directional lunge exercises to simulate the quick stops and directional changes required for net interceptions in pickleball, and its progressive loading, adjusting resistance, and speed to accommodate different skill levels (Behm et al., 2017). However, most existing research has



focused on professional athletes, leaving a gap in Functional Fitness Training program designs tailored for university students. Particularly for young athletes aged 18 to 22, who are still in a phase of physical development, training programs must strike a balance between specialization and the risk of overloading to avoid chronic injuries, such as knee damage, that may arise from early high-intensity specialized training (Lloyd et al., 2015; Myer et al., 2016).

To address the disconnect between physical and skill training, as well as the lack of assessment standards in university pickleball programs, this study proposes an integrated training program based on FFT. The approach aims to achieve a synergistic effect by combining physical and skill training, thereby enhancing athletes' agility, balance, and core strength specific to pickleball (Haff & Triplett, 2015). This method is supported by dynamic systems theory (Kelso, 1995) and skill acquisition theory (Magill & Hall, 1990), and integrated neuromuscular training has been shown to improve performance while reducing injury risks (Myer et al., 2016).

In summary, although pickleball shows broad development prospects as an emerging sport within university athletics, its promotion and popularization still face challenges such as the disconnect between physical and skill training and the absence of standardized assessment criteria. By establishing a specific training program for pickleball, this study aims to enhance students' performance and skill levels, provide scientific evidence and practical pathways for university sports curriculum reform, and pave an innovative way for the teaching models of emerging sports. The inconsistency between traditional training methods and the specific requirements of pickleball, combined with the decline in students' physical fitness and the absence of standardized evaluation systems. These issues have resulted in inadequate development of both skills and physical performance within the context of Chinese universities.

Objectives

The main objective of this research was to develop a specific training program to improve the physical fitness and pickleball performance of athletes at Guangzhou Sports Polytechnic University.

Literature Review

1. Pickleball

Pickleball originated in 1965 on Bainbridge Island, Washington, USA, when three friends, Joel Pritchard, Bill Bell, and Barney McCallum, created the game to provide more entertainment for their families during summer gatherings. They improvised equipment to establish this sport, which combines elements of tennis, badminton, and table tennis. Over time, pickleball evolved into a formal competitive sport, rapidly gaining popularity in the



United States and globally due to its ease of learning and high entertainment value. (USA Pickleball Association, 2023)

The rules of pickleball are crucial for ensuring fairness, safety, and competitiveness in the game. According to the official regulations set by USA Pickleball, the sport's national governing body, pickleball is a hybrid of tennis, badminton, and ping-pong and is currently the fastest-growing sport in America. The rules of pickleball are designed to ensure fairness, smooth gameplay, and strategic depth. During service, the server must stand behind the baseline and use an underhand stroke (with the paddle below waist level) to hit the ball diagonally into the opponent's service court; if the serve touches the net yet still lands in the correct service area, it is called a "let serve." At the start of a rally, both sides must allow the ball to bounce once in their court before hitting it, preventing early aggressive volleys. The standard court measures approximately 20x44 feet with a net height of 36 inches, and the game uses an ABS plastic ball with multiple holes, along with composite paddles. Scoring is typically based on the "only server scores" rule, with games usually played to 11 points (winning by at least 2 points).

2. Technical Performance in Pickleball

Technical performance in pickleball is critical for success in this fast-paced sport, which combines elements of tennis, badminton, and table tennis. Effective execution of foundational skills, such as strokes, serves, and footwork, directly influences competitive outcomes. This section outlines the key technical components of pickleball, their biomechanical and strategic importance, and evidence-based methods for skill development.

1. Forehand and Backhand Strokes: Forehand and backhand strokes form the foundation of pickleball play, enabling offensive and defensive strategies. The forehand drive, executed with a forward swing and transfer of power from the legs to the paddle, is essential for aggressive shots like the third-shot drive, a pivotal transition from defense to offense. The backhand stroke, often used for quick counterattacks, requires compact wrist and elbow movements to maintain control during fast exchanges. Studies emphasize that stroke accuracy and consistency correlate with rally dominance, particularly in doubles play, where shot placement disrupts opponents' positioning. Drills involving repetitive cross-court and down-the-line shots, combined with real-time feedback, enhance muscle memory and adaptability to varying ball speeds.

2. Serve: The serve initiates play and sets the tone for rallies. An effective pickleball serve prioritizes depth and placement rather than speed, as per the sport's rules limiting overhead serves. Topspin or slice serves can be used to challenge opponents' returns, particularly targeting their backhand or forcing them away from the non-volley zone (NVZ) (Johnson & Nilges, 2018).



3. Dinking and Net Play: The dink, a soft shot executed near the NVZ, is a strategic tool to reset rallies and force opponents into errors. Proper dinking requires precise paddle control, minimal backswing, and reliance on finesse rather than power. Research highlights that players who master dinking techniques exhibit higher rally endurance and tactical adaptability. Drills such as cross-court dinking exchanges and “dink-and-drop” sequences improve touch and consistency. Net play, including volleys and blocks, demands quick reflexes and compact strokes to counter fast-paced shots. Footwork drills, such as lateral shuffles and split-step practices, are integrated to enhance readiness at the net.

4. Footwork: Efficient footwork is vital for maintaining balance and positioning during rapid directional changes. Pickleball’s compact court requires athletes to master lateral movements, split-step timing, and quick transitions between the baseline and NVZ. Studies comparing pickleball to tennis note that shorter reaction windows in pickleball necessitate faster acceleration and deceleration. Agility ladder drills, cone patterns, and shadowing exercises are commonly used to improve multidirectional speed. Additionally, anticipatory footwork predicting opponents’ shots based on paddle angle and body positioning enhances defensive and offensive efficiency.

5. Spin and Deception Techniques: While less spin-centric than table tennis, pickleball allows strategic use of slice and topspin to manipulate ball trajectory. A backhand slice can slow down rallies, while topspin drives increase ball speed after the bounce, pressuring opponents into defensive positions (Gonzalez, 2019). Deceptive techniques, such as disguising drop shots as drives, rely on subtle wrist movements and body positioning. Video analysis tools help athletes refine spin mechanics and identify patterns in opponents’ weaknesses.

6. Third-Shot Strategies: The third-shot drop, a hallmark of advanced play, involves softly arcing the ball into the opponent’s NVZ to transition from the baseline to the net. This shot demands precise paddle angle control and touch to avoid pop-ups. Research indicates that successful third-shot execution correlates with higher point-winning percentages in competitive matches. Drills combining third-shot drops with follow-up volleys simulate real-game scenarios, fostering tactical decision-making.

7. Doubles-Specific Skills: In doubles, teamwork and communication are critical. Skills like stacking (positioning adjustments to optimize dominant hands) and poaching (intercepting cross-court shots) require synchronized movement and anticipation. Studies on racket sports underscore the importance of verbal and non-verbal cues in doubles coordination. Partner-based drills, such as alternating poaches and targeted communication exercises, enhance these dynamics.

Conceptual Framework

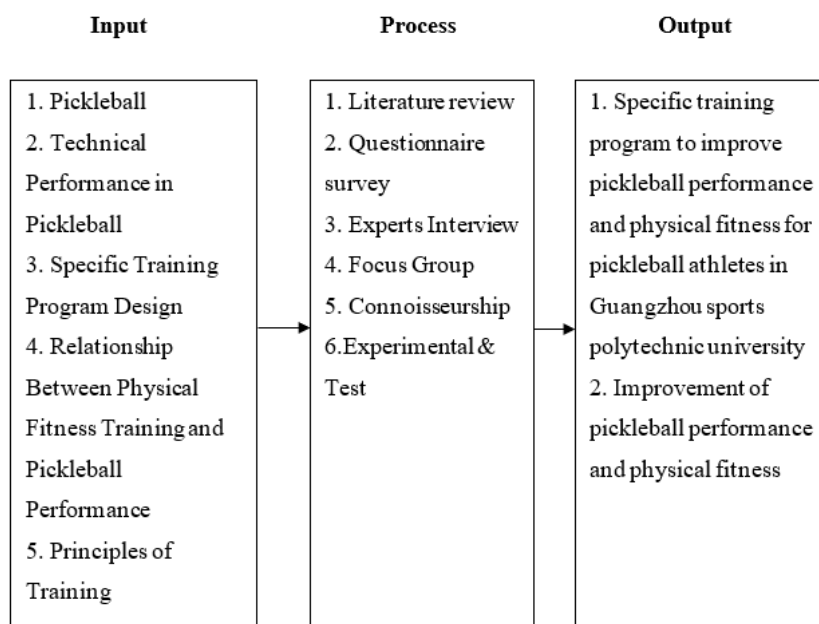


Figure 1 Conceptual Framework

Methodology

Population

The population of this study consists of Guangzhou Sports Polytechnic University's pickleball team. The research population was 120 male pickleball athletes, aged between 18-22 years. All athletes possess foundational pickleball skills and regularly participate in university-level competitions.

Sample for experimental

The researcher selected 30 athletes from the athletes' population, aged 18-22 years, who were chosen based on their need to improve specific performance, their commitment to participating in structured training sessions, and their interest in participating in the experiment. The selected 30 athletes underwent a test of physical fitness. Based on their test results, the athletes were ranked and then used the systematic method divided into two groups: an experimental group of 15 athletes and a control group of 15 athletes.

Inclusion Criteria:

1. Male athletes aged between 18 and 22 years.
2. Active members of the Guangzhou Sports Polytechnic University's pickleball team.
3. Possess foundational pickleball skills as demonstrated by regular participation in university-level competitions.
4. Demonstrate a willingness to participate in the full duration of the 8-week training program.
5. Be in good health and have not had any injuries within 3 months.

Exclusion Criteria:

1. Presence of any musculoskeletal injury or chronic disease that limits physical activity within 3 months.
2. Inability to commit to the full training and testing schedule due to academic, health, or personal reasons.
3. Injuries or withdrawals due to personal reasons

These criteria were implemented to ensure the reliability of the experimental outcomes and to minimize confounding variables that could affect the athletes' performance or the validity of the training intervention.

Research Participants

Using the purposive sampling method:

1. 5 experts for an interview to design and draft the specific training program. These experts included: one sports science professor, two pickleball coaches, one referee specializing in pickleball, and one professional pickleball athlete. The above experts have been in the pickleball industry for more than five years.
2. 9 experts for the focus group method to offer guidance and suggestions for the Training Program Improvement. The group consisted of three sports scientists, one physical fitness training expert, two university pickleball professors, two pickleball coaches, and one international pickleball athlete. The above experts have been in the pickleball industry for more than five years.
3. 7 Experts for the connoisseurship method to confirm the feasibility of a specific training program. Including one sports science professor and two experienced pickleball coaches, one referee specializing in pickleball, and three professional sport scientists, the above experts have been in their industries for more than five years.

Research Instrument

Expert Interview Questionnaire

A structured interview protocol was developed to gather insights from 5 pickleball coaches and sports scientists specializing in racket sports. These experts provided insights and guidance for tailoring the training plan to meet the athletes' needs (IOC=0.90).

Focus Group Outline

A panel of 9 experts (three sports scientists, one physical fitness expert, two university pickleball professors, two pickleball coaches, and one Pickleball International athlete) was invited to discuss and refine the content of the specific training program to improve athletes' pickleball performance and physical fitness via this focus group outline.

Connoisseurship outline

The finalized training program was subjected to review by 7 experts in the field to assess its feasibility and scientific validity. Their evaluations ensured the program's practicality and alignment with the research objectives.

Specific Training Program

A customized training plan designed to enhance pickleball performance and physical fitness, including forehand and backhand stroke accuracy, ball speed, and court movement efficiency. The plan detailed skill training, agility, and lower limb strength, reaction-time, and cardiopulmonary endurance training program components, frequency of sessions, and recovery schedules.

Pickleball Performance Tests

1. Forehand and backhand stroke accuracy Test 40 shots toward 1 m×1 m baseline/NVZ targets; ≥70% success = proficiency (Carnot, P. 2004)
2. Third-shot Drop Consistency Test: 15 attempts requiring drops <30 cm net clearance and within 0.5 m of the NVZ line (Carnot, P. 2004).
3. Pickleball Shot Speed Test: This protocol uses radar guns or high-speed cameras to measure serve, drive, and volley speeds, combined with scoring benchmarks to evaluate players' shot power and technical performance (Kovacs, M.S., & Ellenbecker, T.S., 2008).
4. Game-Simulation Movement Test: The coach or ball machine will randomly serve the ball to different positions on the court. The player moves quickly and hits back depending on the position of the ball (Sheppard, J. M., & Young, W. B., 2006).

Physical Fitness tests

1. Agility (5-10-5 shuttle run with infrared timing) (Semenick, 1990)
2. Lower limb strength (Back and leg dynamometer) (Heyward, 2010)
3. Cardiopulmonary endurance (Yo-Yo Intermittent Recovery Test Level 1 distance) (Bangsbo et al., 2008)
4. Reaction-time (Light Reaction Test using BlazePod) (Schmidt & Lee, 2019)

Data Collection

1. Expert Interviews: One-on-one interviews with experts in the field of pickleball were carried out. The discussions revolved around the research objectives, gathering insights, experiences, and recommendations for developing the specific training program. (Interviews were audio-recorded, transcribed, and coded for thematic analysis.)
2. Focus Group Discussions: A representative group of individuals from relevant fields participated in guided discussions. These sessions aimed to elicit collective opinions and feedback on the proposed training program by fostering interactive dialogue on specific aspects of its design and implementation.

3. Invite experts to connoisseurship-specific training programs subjected to review by seven experts in the field to assess their feasibility and scientific validity.

4. Experimental phase: All participants in the experiment signed voluntary consent forms. Basic demographic and physical information, including height, weight, age, and initial performance metrics, was collected. The study spanned 8 weeks, with training conducted three days per week. The experimental group followed the specialized training program on Monday, Wednesday, and Friday for 90 minutes per session, while the control group adopted traditional training methods on the same dates at 2 p.m. Both groups rested on Sundays.

Pre-test (Before Training): Before initiating the training program, baseline data were collected on the athletes' agility, lower limb mobility, core stability, reaction speed, and performance in standard pickleball drills (such as consecutive volleys or serve accuracy). An initial assessment of pickleball skills was conducted to evaluate the athletes' stroke techniques, footwork, and game rhythm, establishing a foundational skill baseline.

Mid-term Test (After 4 Weeks): At the four-week midpoint evaluation, measurements of agility, footwork, core stability, reaction speed, and performance in pickleball drills were recorded to monitor training progress. Following the mid-term training phase, assessments of the athletes' pickleball techniques and match pace were conducted, noting improvements in technical details and responsiveness.

Post-test (After 8 Weeks): Upon completion of the eight-week training program, a comprehensive evaluation was performed, collecting data on agility, footwork, core stability, reaction speed, and performance in pickleball drills (e.g., consistency in volleys and serve accuracy) to determine the overall effectiveness of the training regimen. Final test results were compared with previous data to assess the impact of the training intervention on enhancing pickleball skills and performance.

Data Analysis

1. Descriptive statistical analysis to summarize the basic characteristics and data distribution of the sample.

2. Content analysis: Analysis of the answers of the experts' interview data, consulting results from the focus group method, and connoisseurship method data.

3. The independent sample t-test was used for comparison of data between groups. ($P < 0.05$, which means it has a significant difference; $P > 0.05$ means no significant difference). Comparison analysis within groups used One-Way repeated ANOVA and post hoc (Bonferroni).

4. Data interpretation: A five-point Likert scale was applied in this study to analyze the data from the questionnaire survey and connoisseurship evaluation.

Results

Incorporating these insights, the draft program was revised into the final draft of an 8-week specific training program. Compared with the earlier version, the optimized program strengthens recovery and injury-prevention strategies, introduces dual-task reaction training, and applies progressive resistance methods in physical conditioning. Overall, the revised program is more comprehensive, scientifically grounded, and better aligned with both the physical fitness and technical performance needs of university pickleball athletes, thereby providing a solid foundation for the subsequent experimental implementation discussed in the next section.

Table 1 The comparison of pickleball performance on pre-test between the control group and the experimental group by using an independent sample t-test (n=15)

Pickleball Performance	Experimental (Mean $\pm$ SD)	Control (Mean $\pm$ SD)	t	p
Forehand and Backhand Stroke Accuracy	60.1 $\pm$ 5.80	59.4 $\pm$ 6.10	0.35	0.729
Third-Shot Drop Consistency	54.6 $\pm$ 6.40	56.2 $\pm$ 6.90	-0.93	0.358
Shot Speed	72.3 $\pm$ 7.20	73.6 $\pm$ 5.90	-0.76	0.450
Game-Simulation Movement (sec)	6.88 $\pm$ 0.49	6.92 $\pm$ 0.51	-0.28	0.782

p < 0.05

Table 1 found that, the independent-samples t-test results demonstrated that at the pre-test stage, no significant differences were found between the experimental and control groups across all four pickleball performance indicators, including stroke accuracy (t = 0.35, p = 0.729), third-shot drop consistency (t = -0.93, p = 0.358), shot speed (t = -0.76, p = 0.450), and game-simulation movement time (t = -0.28, p = 0.782). This indicates that the two groups were comparable at baseline.

Table 2 The comparison of pickleball performance on post-test between the control group and the experimental group by using an independent sample t-test (n=15)

Pickleball Performance	Experimental (Mean $\pm$ SD)	Control (Mean $\pm$ SD)	t	p
Forehand and Backhand Stroke Accuracy	77.0 $\pm$ 5.10	64.3 $\pm$ 4.60	10.00	0.01**
Third-Shot Drop Consistency	73.7 $\pm$ 5.20	61.0 $\pm$ 5.90	8.65	0.01**
Shot Speed	84.5 $\pm$ 6.70	75.3 $\pm$ 6.70	5.17	0.01**
Game-Simulation Movement (sec)	5.81 $\pm$ 0.29	6.57 $\pm$ 0.50	-7.01	0.01**

*p < 0.05

Table 2 found that, by the post-test stage, the differences between groups became highly significant across all performance measures. The experimental group demonstrated superior stroke accuracy ($t = 10.00$, $p < 0.01$), third-shot drop consistency ($t = 8.65$, $p < 0.01$), shot speed ($t = 5.17$, $p < 0.01$), and game-simulation movement time ($t = -7.01$, $p < 0.01$), indicating robust and consistent gains compared to the control group.

Table 3 The comparison of physical fitness on pre-test between the control group and the experimental group by using an independent sample t-test ($n=15$)

Physical Fitness	Experimental (Mean $\pm$ SD)	Control (Mean $\pm$ SD)	t	p
Agility (5-10-5, sec)	5.23 $\pm$ 0.41	5.24 $\pm$ 0.42	-0.08	0.935
Lower Limb Strength (kg)	142.5 $\pm$ 12.70	143.0 $\pm$ 12.80	-0.11	0.912
Cardiopulmonary Endurance (Yo-Yo, m)	1120 $\pm$ 15	1115 $\pm$ 15	0.09	0.926
Reaction Time (ms)	428 $\pm$ 35	429 $\pm$ 36	-0.08	0.938

$p < 0.05$

Table 3 found that, the results indicated that at the pre-test stage, no significant differences were observed between the experimental and control groups across all physical fitness indicators, including agility ($t = -0.08$, $p = 0.935$), lower limb strength ($t = -0.11$, $p = 0.912$), cardiopulmonary endurance ($t = 0.09$, $p = 0.926$), and reaction time ($t = -0.08$, $p = 0.938$). This confirms that the two groups were comparable at baseline.

Table 4 The comparison of physical fitness on post-test between the control group and the experimental group by using an independent sample t-test ($n=15$)

Physical Fitness	Experimental (Mean $\pm$ SD)	Control (Mean $\pm$ SD)	t	p
Agility (5-10-5, sec)	4.55 $\pm$ 0.35	5.12 $\pm$ 0.39	-4.68	0.01**
Lower Limb Strength (kg)	169.7 $\pm$ 12.40	149.2 $\pm$ 12.30	4.49	0.01**
Cardiopulmonary Endurance (Yo-Yo, m)	1610 $\pm$ 17	1205 $\pm$ 16	6.90	0.01**
Reaction Time (ms)	361 $\pm$ 28	414 $\pm$ 33	-4.76	0.01**

* $p < 0.05$

Table 4 found that, in the post-test phase, the differences between groups became highly significant across all physical fitness measures. The experimental group showed markedly better agility ($t = -4.68$, $p < 0.01$), lower limb strength ($t = 4.49$, $p < 0.01$), cardiopulmonary endurance ($t = 6.90$, $p < 0.01$), and reaction time ($t = -4.76$, $p < 0.01$) compared to the control group.

The comparison between pre-, mid-, and post-test results of pickleball performance and physical fitness of students within the experimental group

Table 5 The comparison of forehand and backhand stroke accuracy on pre-test, mid-test, and post-test within the experimental group by using Repeated measures ANOVA (n=15)

Source of Variant	df	SS	MS	F	p
Time	2	122.54	61.27	61.27	0.01**
(Within-Subject Effects)					
Error	28	28.00	1.00		
Total	44	150.54			

*p < 0.05

Table 5 presents the results of a one-way repeated measures ANOVA for the forehand and backhand stroke accuracy within the experimental group. The data show a highly significant between-group effect ($F = 61.27$, $p < 0.01$), indicating that the students' forehand and backhand stroke accuracy underwent statistically significant overall changes across the pre-test, mid-test, and post-test phases during the 8-week training program. This demonstrates that the training intervention had a decisive impact on improving this skill.

Table 6 The comparison of forehand and backhand stroke accuracy on pre-test, mid-test, and post-test within the experimental group, comparing the two groups by using the Bonferroni test (n = 15)

Variable	Test	Pre-test	Mid-test	Post-test
Forehand and Backhand	Pre-test	-	-7.60**	-16.90**
Stroke Accuracy	Mid-test	-	-	-9.30**
	Post-test	-	-	-

p < 0.05

Table 6 found that, displays pairwise comparisons of forehand and backhand stroke accuracy using the Bonferroni post-hoc test. The results reveal a significant difference between the pre-test and mid-test ($t = -7.60$, $p < 0.05$), indicating that the first 4 weeks of training effectively enhanced the skill. A significant difference was also found between the mid-test and post-test ($t = -9.30$, $p < 0.01$), demonstrating further notable improvement during the latter 4 weeks of training. The most pronounced difference was between the pre-test and post-test ($t = -16.90$, $p < 0.05$).

Table 7 The comparison of third shot drop consistency on pre-test, mid-test, and post-test within the experimental group by using Repeated measures ANOVA (n=15)

Source of Variant	df	SS	MS	F	p
Time	2	132.84	66.42	66.42	0.01**

Source of Variant	df	SS	MS	F	p
(Within-Subject Effects)					
Error	28	28.00	1.00		
Total	44	160.84			

*p < 0.05

Table 7 found that the results of a one-way repeated measures ANOVA for the third-shot drop consistency within the experimental group. The data show a highly significant between-group effect ($F = 66.42$, $p < 0.01$), indicating that the students' third-shot drop consistency underwent statistically significant overall changes across the pre-test, mid-test, and post-test phases during the 8-week training program.

Table 8 The comparison of third-shot drop consistency on pre-test, mid-test, and post-test within the experimental group, comparing two groups by using the Bonferroni test ($n = 15$)

Variable	Test	Pre-test	Mid-test	Post-test
Third-Shot Drop Consistency	Pre-test	-	-8.30**	-19.10**
	Mid-test	-	-	-10.80**
	Post-test	-	-	-

* p < 0.05

Table 8 found that, displays pairwise comparisons of third-shot drop consistency using the Bonferroni post-hoc test. The results reveal a significant difference between the pre-test and mid-test ($t = -8.30$, $p < 0.05$), indicating that the first 4 weeks of training significantly improved drop consistency. A significant difference was also found between the mid-test and post-test ($t = -10.80$, $p < 0.05$), demonstrating continued and marked progress during the latter 4 weeks of training. The most pronounced difference was between the pre-test and post-test ($t = -19.10$, $p < 0.05$).

Table 9 The comparison of shot speed on pre-test, mid-test, and post-test within the experimental group by using Repeated measures ANOVA ($n=15$)

Source of Variant	df	SS	MS	F	p
Time	2	108.36	54.18	54.18	0.01**
(Within-Subject Effects)					
Error	28	28.00	1.00		
Total	44	136.36			

* p < 0.05

Table 9 presents the results of a one-way repeated measures ANOVA for shot speed within the experimental group. The data show a highly significant between-group effect ($F = 54.18$, $p < 0.01$), indicating that the students' shot speed underwent statistically significant

overall changes across the pre-test, mid-test, and post-test phases during the 8-week training program.

Table 10 The comparison of shot speed on pre-test, mid-test, and post-test within the experimental group, comparing two groups by using the Bonferroni test (n = 15)

Variable	Test	Pre-test	Mid-test	Post-test
Shot Speed	Pre-test	-	-6.60**	-12.20**
	Mid-test	-	-	-5.60**
	Post-test	-	-	-

* $p < 0.05$

Table 10 found that, displays pairwise comparisons of shot speed using the Bonferroni post-hoc test. The results reveal a significant difference between the pre-test and mid-test ($t = -6.60$, $p < 0.05$), indicating that the first 4 weeks of training significantly increased shot speed. A significant difference was also found between the mid-test and post-test ($t = -5.60$, $p < 0.05$), showing that shot speed was further accelerated during the latter 4 weeks of training. The significant difference between the pre-test and post-test ($t = -12.20$, $p < 0.05$).

Table 11 The comparison of game-simulation movement on pre-test, mid-test, and post-test within the experimental group by using Repeated measures ANOVA (n=15)

Source of Variant	df	SS	MS	F	p
Time	2	117.90	58.95	58.95	0.01**
(Within-Subject Effects)					
Error	28	28.00	1.00		
Total	44	145.90			

* $p < 0.05$

Table 11 presents the results of a one-way repeated measures ANOVA for game-simulation movement efficiency within the experimental group. The data show a highly significant between-group effect ($F = 58.95$, $p < 0.01$), indicating that the time taken by the students to complete on-court movement tasks (i.e., movement efficiency) underwent statistically significant overall changes across the pre-test, mid-test, and post-test phases during the 8-week training program.

Table 12 The comparison of game-simulation movement on pre-test, mid-test, and post-test within the experimental group, comparing two groups by using the Bonferroni test (n = 15)

Variable	Test	Pre-test	Mid-test	Post-test
Game-Simulation	Pre-test	-	0.40**	1.07**
Movement (sec)	Mid-test	-	-	0.67**

Variable	Test	Pre-test	Mid-test	Post-test
	Post-test	-	-	-

* $p < 0.05$

Table 12 found that, displays pairwise comparisons of game-simulation movement time using the Bonferroni post-hoc test. The results reveal a significant difference between the pre-test and mid-test ($t = 0.40$, $p < 0.05$), indicating that the first 4 weeks of training significantly reduced movement time, thereby improving movement efficiency. A significant difference was also found between the mid-test and post-test ($t = 0.67$, $p < 0.05$), showing that movement efficiency was further optimized during the latter 4 weeks of training. The significant difference between the pre-test and post-test ($t = 1.07$, $p < 0.05$).

Table 13 The comparison of agility on pre-test, mid-test, and post-test within the experimental group by using Repeated measures ANOVA (n=15)

Source of Variant	df	SS	MS	F	p
Time	2	94.52	47.26	47.26	0.01**
(Within-Subject Effects)					
Error	28	28.00	1.00		
Total	44	122.52			

* $p < 0.05$

Table 13 presents the results of a one-way repeated measures ANOVA for agility (5-10-5 test) within the experimental group. The data show a highly significant between-group effect ($F = 47.26$, $p < 0.01$), indicating that the students' agility underwent statistically significant overall improvements across the pre-test, mid-test, and post-test phases during the 8-week training program.

Table 14 The comparison of Agility on pre-test, mid-test, and post-test within the experimental group, comparing two groups by using the Bonferroni test (n = 15)

Variable	Test	Pre-test	Mid-test	Post-test
Agility (5-10-5, sec)	Pre-test	-	0.34**	0.68**
	Mid-test	-	-	0.34**
	Post-test	-	-	-

* $p < 0.05$

Table 14 found that, displays pairwise comparisons of agility using the Bonferroni post-hoc test. The results reveal significant improvements in agility performance between all testing phases: from pre-test to mid-test ($t = 0.34$, $p < 0.05$), from mid-test to post-test ($t = 0.34$, $p < 0.05$), and from pre-test to post-test ($t = 0.68$, $p < 0.05$).

Table 15: The comparison of Lower Limb Strength on pre-test, mid-test, and post-test within the experimental group by using Repeated measures ANOVA (n=15)

Source of Variant	df	SS	MS	F	p
Time (Within-Subject Effects)	2	138.28	69.14	69.14	0.01*
Error	28	28.00	1.00		
Total	44	166.28			

* $p < 0.05$

Table 15 presents the results of a one-way repeated measures ANOVA for lower limb strength within the experimental group. The data show a highly significant between-group effect ($F = 69.14$, $p < 0.01$), indicating that the students' lower limb strength demonstrated statistically significant overall improvements across the three testing phases.

Table 16: The comparison of Lower Limb Strength on pre-test, mid-test, and post-test within the experimental group, comparing the two groups by using the Bonferroni test (n = 15)

Variable	Test	Pre-test	Mid-test	Post-test
Lower Limb Strength (kg)	Pre-test	-	-13.90**	-27.20**
	Mid-test	-	-	-13.30**
	Post-test)	-	-	-

* $p < 0.05$

Table 16 found that, displays pairwise comparisons of lower limb strength using the Bonferroni post-hoc test. The results show significant strength gains between all testing intervals: from pre-test to mid-test ($t = -13.90$, $p < 0.05$), from mid-test to post-test ($t = -13.30$, $p < 0.05$), and most substantially from pre-test to post-test ($t = -27.20$, $p < 0.05$).

Table 17: The comparison of Cardiopulmonary Endurance on pre-test, mid-test, and post-test within the experimental group by using Repeated measures ANOVA (n=15)

Source of Variant	df	SS	MS	F	p
Time (Within-Subject Effects)	2	144.72	72.36	72.36	0.01**
Error	28	28.00	1.00		
Total	44	172.72			

* $p < 0.05$

Table 17 presents the results of a one-way repeated measures ANOVA for cardiopulmonary endurance within the experimental group. The data show a highly significant between-group

effect ($F = 72.36$, $p < 0.01$), indicating that the students' cardiopulmonary endurance underwent statistically significant overall improvements across the three testing phases.

Table 18 The comparison of Cardiopulmonary Endurance on pre-test, mid-test, and post-test within the experimental group, comparing two groups by using the Bonferroni test ($n = 15$)

Variable	Test	Pre-test	Mid-test	Post-test
Cardiopulmonary Endurance (m)	Pre-test	-	230.00**	490.00**
	Mid-test	-	-	-260.00**
	Post-test	-	-	-

* $p < 0.05$

Table 18 found that, displays pairwise comparisons of cardiopulmonary endurance using the Bonferroni post-hoc test. The results reveal significant improvements in endurance between all testing phases: from pre-test to mid-test ($t = 230$, $p < 0.05$), from mid-test to post-test ($t = -260$, $p < 0.05$), and most substantially from pre-test to post-test ($t = 490$, $p < 0.05$).

Table 19 The comparison of Reaction Time on pre-test, mid-test, and post-test within the experimental group by using Repeated measures ANOVA ($n=15$)

Source of Variant	df	SS	MS	F	p
Time (Within-Subject Effects)	2	130.44	65.22	65.22	0.01**
Error	28	28.00	1.00		
Total	44	158.44			

* $p < 0.05$

Table 19 found that, presents the results of a one-way repeated measures ANOVA for reaction time within the experimental group. The data show a highly significant between-group effect ($F = 65.22$, $p < 0.01$), indicating that the students' reaction time underwent statistically significant overall improvements across the three testing phases.

Table 20 The comparison of Reaction Time on pre-test, mid-test, and post-test within the experimental group, comparing two groups by using the Bonferroni test ($n = 15$)

Variable	Test	Pre-test	Mid-test	Post-test
Reaction Time (ms)	Pre-test	-	36.00**	67.00**
	Mid-test	-	-	31.00**
	Post-test	-	-	-

* $p < 0.05$

Table 20 found that, displays pairwise comparisons of reaction time using the Bonferroni post-hoc test. The results show significant improvements in reaction time between all testing

intervals: from pre-test to mid-test ($t = 36.00$, $p < 0.05$), from mid-test to post-test ($t = 31.00$, $p < 0.05$), and most substantially from pre-test to post-test ($t = 67.00$, $p < 0.05$). These findings demonstrate that the training program progressively enhanced athletes' reaction capabilities throughout the intervention period.

Overall, these findings demonstrate that the intervention effectively enhanced participants' physical fitness capacities in parallel with their pickleball performance. It can be confirmed that the experimental group experienced consistent and progressive improvements across both technical performance and physical fitness domains. Early benefits appeared within the first four weeks, while more substantial gains were achieved by the end of the eight-week program, underscoring the effectiveness of the structured and progressive training design.

Discussion

The specific training program integrated multiple components involving physical fitness (agility, lower limb strength, cardiopulmonary endurance, and reaction time) as well as performance, including technical and tactical pickleball skills, such as stroke accuracy, third shot drop consistency, shot speed, and game-simulation drills. This holistic approach is strongly supported by the literature in racket sports. For instance, Sheppard and Young (2006) confirmed the central role of agility in game performance, while Castagna et al. (2008) emphasized the importance of endurance for sustaining rallies. Strength and plyometric training were also essential elements. Studies by Meylan (2009) demonstrated that lower-limb plyometrics significantly improve explosive movements, which are critical for quick directional changes in pickleball. The strength and conditioning coach in our expert panel echoed this point, highlighting the necessity of progressive overload in resistance training to maximize performance gains.

At the pre-test stage, no significant differences were observed between the two groups, indicating comparable baseline levels. By the mid-test (after four weeks), the experimental group began to show advantages in stroke accuracy, agility, endurance, and other measures, but the differences remained moderate. This may be explained by the limited time for physiological adaptations; previous studies have shown that improvements in aerobic capacity and muscular strength often require at least 6-8 weeks of consistent training (Buchheit & Laursen, 2013; Hoffman et al., 2009). Expert opinions in this study, particularly from the sports scientist and sports medicine specialist, also suggested that short-term improvements are typically limited to neuromuscular coordination and technical consistency. By the post-test stage (after eight weeks), the differences between groups became highly significant across all variables ($p < 0.001$). The experimental group showed marked improvements in technical skills (stroke accuracy, third-shot drop, shot speed, game-simulation movement) and physical fitness (agility, strength, endurance, reaction time). These robust results reflect the cumulative effects

of progressive overload and structured periodization, which allowed for steady and accelerating gains. Similar findings have been reported by Ramirez-Campillo et al. (2014) and Meylan and Malatesta (2009) for strength and plyometric training.

Recommendations

Recommendation for Applications Based on the Findings

1. Coaches should systematically incorporate agility ladder drills, shuttle runs, plyometric training, and resistance exercises to enhance agility, lower-limb strength, cardiopulmonary endurance, and reaction time, as these were identified as the weakest areas in both athlete and coach questionnaires.

2. Training should emphasize forehand and backhand stroke accuracy, third-shot drop consistency, serve reliability, and shot speed, as these were areas where athletes showed significant improvement and which experts consistently highlighted as performance determinants.

3. Coaches should maintain a progressive approach, gradually increasing training intensity (70-85% 1RM; 70-85% HRmax) and extending session duration (90-100 minutes), ensuring athletes adapt physiologically without overtraining.

Recommendations for Future Research

1. Future studies should include larger and more diverse samples across different universities, regions, and genders to enhance the generalizability of the findings.

2. Conduct longitudinal follow-ups after the training program to examine whether improvements in physical fitness and pickleball performance are maintained over time.

3. Future research could compare the proposed program with other training approaches, such as small-sided games or ecological dynamics-based practice, to determine the relative effectiveness of different pedagogical models.

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