

## RESEARCH ARTICLE



# A Quasi-Experimental Study of Synergistic Impact of Functional Conditioning on Biomotor Proficiencies in Adolescent Female Tennis Athletes

Dhanalakshmi M<sup>\*1</sup>, Bobby N N<sup>1</sup>, Arunselvan D<sup>2</sup>

<sup>1</sup> Department of Physiotherapy, Thanthai Roever College of Physiotherapy, Perambalur, Tamil Nadu, India

<sup>2</sup> Department of Physiotherapy, Sri Vijay Vidyalaya College of Physiotherapy, Dharmapuri, Tamil Nadu, India

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**Abstract:** Adolescent female tennis players navigate a unique developmental phase where neuromuscular maturation and sport-specific physical demands intersect. Traditional training models often isolate physical attributes, potentially failing to address the multi-planar, high-intensity requirements of competitive tennis. This research work evaluates the efficacy of an 8-week functional training intervention compared to routine tennis practice in optimizing biomotor abilities. Twenty female athletes aged 14–18 were partitioned into a control group (n = 10) receiving standard technical training and an experimental group (n = 10) receiving a hybrid program of functional conditioning and routine practice. Metrics for speed, agility, flexibility, muscular strength, and anaerobic power were obtained through standardized testing protocols including the 10-m sprint, agility T-test, sit-and-reach, hand grip dynamometry, vertical jump, and hopping tests. Data analysis indicates that the control group achieved no significant statistical gains across the biomotor spectrum ( $p > 0.05$ ). Conversely, the experimental group showed profound enhancements in all measured variables, particularly in agility and muscular strength ( $p < 0.0001$ ). The comparative outcomes validate functional training as a superior modality for enhancing kinetic chain efficiency and explosive power. These results support the combination of multi-joint, sport-specific movement patterns into adolescent athletic conditioning to maximize physical development and competitive readiness.

**Keywords:** Functional conditioning; Neuromuscular efficiency; Biomotor development; Adolescent tennis; Kinetic chain optimization.

## 1. Introduction

The evolution of modern sports conditioning indicates the transition from isolated muscle strengthening to the development of integrated, coordinated movement patterns. This paradigm shift has led to the emergence of functional training, a methodology characterized by multi-joint and multi-planar exercises that mirror the physiological and mechanical demands of specific athletic tasks [1]. Unlike traditional resistance protocols, functional conditioning targets neuromuscular efficiency and movement quality by engaging multiple physiological systems simultaneously through dynamic and high-intensity modalities [2, 3].

Physical fitness in the competitive athlete is a manifestation of specialized biological adaptations to systematic training stimuli. These adaptations are categorized as biomotor abilities fundamental physical qualities including strength, speed, endurance, flexibility, and coordination that dictate motor task efficacy [4]. During the critical window of adolescence, the neuromuscular system is highly plastic, making it an optimal period for the acquisition of complex motor skills and the enhancement of physical capacities. The principle of specificity dictates that the nature of the training stimulus determines the unique physiological adaptations of the athlete [5]. Consequently, training interventions that utilize task-specific movements are theorized to provide a more effective transfer of physical gains to sport-specific performance [6].

Tennis is characterized by high-intensity, intermittent activity patterns that require a seamless integration of aerobic and anaerobic energy systems [7]. Performance hinges on the athlete's ability to execute explosive movements, including rapid acceleration, deceleration, and frequent changes of direction, coupled with high-velocity strokes [8]. These actions necessitate robust biomotor proficiencies, particularly agility, explosive power, and dynamic stability. Conventional training often separates technical skill acquisition from physical conditioning, which may not adequately address the complex, multidimensional nature of tennis-specific movements [9].

\* Corresponding author: Dhanalakshmi M

Functional training aims to bridge the gap between strength and movement by focusing on the kinetic chain. This approach improves proprioception and dynamic balance by utilizing exercises that require core stabilization while performing limb movements [10, 11]. For the adolescent tennis player, such training may improve the efficiency of force transfer from the lower extremities through the trunk and into the upper limbs during serve and groundstroke execution. Despite the theoretical advantages, empirical evidence regarding the impact of these interventions on the biomotor profiles of female adolescent tennis players remains sparse [12].

## 2. Methodology

### 2.1. Study Design and Ethical Considerations

A quasi-experimental pre-test and post-test design was employed to assess the outcomes of an 8-week intervention. The study was conducted in 2021 at Thanthai Roever College of Physiotherapy, India. Ethical clearance was obtained from the Institutional Ethics Committee (Ref No: TRCP/IEC/2025/042), and the research adhered to the principles of the Declaration of Helsinki. All participants and their legal guardians provided written informed consent following a comprehensive briefing on the study's objectives and potential risks.

### 2.2. Participant Selection and Stratification

Twenty female tennis players were selected based on specific inclusion criteria: age between 14 and 18 years, a minimum of six months of active playing experience, and a commitment to the 8-week protocol. Exclusion criteria were strictly enforced to eliminate confounding variables, including any history of lower limb injury within the six months preceding the study, pre-existing musculoskeletal disorders, or known cardiovascular conditions. Participants were allocated into two groups of ten: the Control Group (CG) and the Experimental Group (EG).

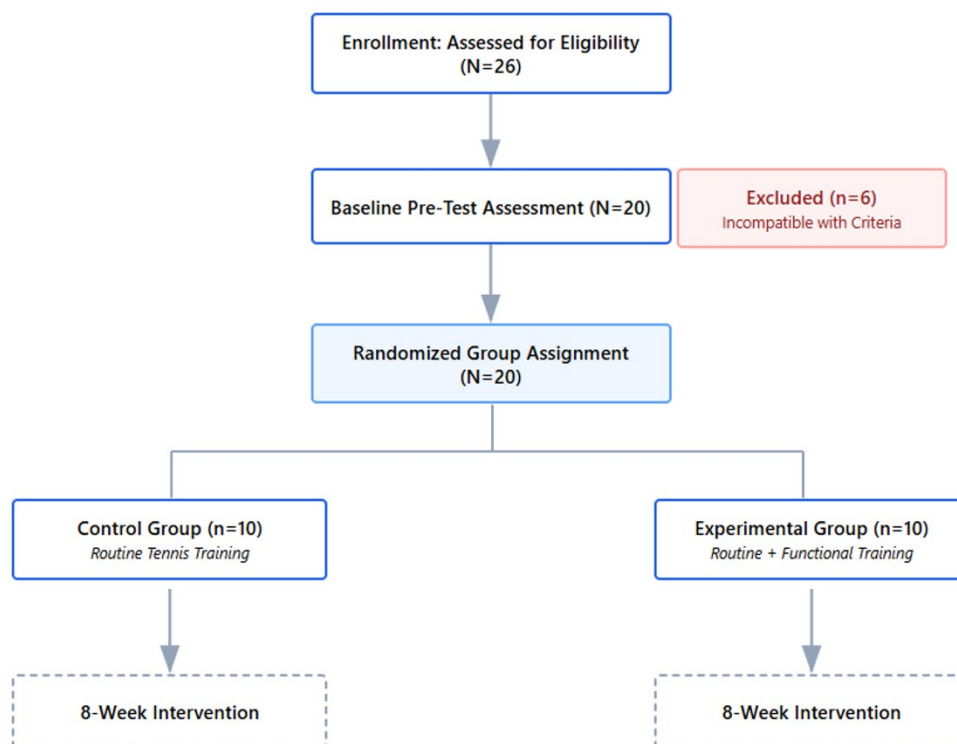


Figure 1. CONSORT Flow Diagram of the Study

### 2.3. Biomotor Assessment Protocols

Standardized testing was conducted over a two-day period both before and after the 8-week intervention. To ensure consistency, all tests were performed in the same environment after a standardized 10-minute warm-up consisting of low-intensity jogging and dynamic stretching.

### 2.3.1. Linear Speed and Agility Metrics

Linear speed was quantified using the 10-meter sprint test. Participants assumed a standing start and performed three maximal-effort sprints with a stopwatch recording the duration; the fastest trial was utilized for analysis. Agility was evaluated via the standardized T-test, which requires the athlete to sprint forward, move laterally to both sides, and back-pedal to the starting point. This test is a critical indicator of an athlete's ability to decelerate and change direction, reflecting the lateral movement demands of tennis [13].

### 2.3.2. Muscular Strength and Explosive Power

Hand grip strength, a surrogate measure for overall upper-body muscular strength, was assessed using a calibrated digital hand dynamometer (Model 101 LCD). Participants performed maximal voluntary contractions with the arm extended, and the highest value in kilograms was recorded. Lower limb explosive power was measured through the Vertical Jump Test, calculating the discrepancy between standing reach and peak jump height [14]. Anaerobic power was further assessed using a 60-second hopping test to evaluate repetitive plyometric endurance.

### 2.3.3. Flexibility Assessment

Flexibility was determined using the sit-and-reach test. Participants maintained a long-sitting position with knees locked and reached forward along a measuring scale. The distance reached beyond the baseline was recorded in centimeters, providing a measure of posterior chain and lumbar mobility [15].

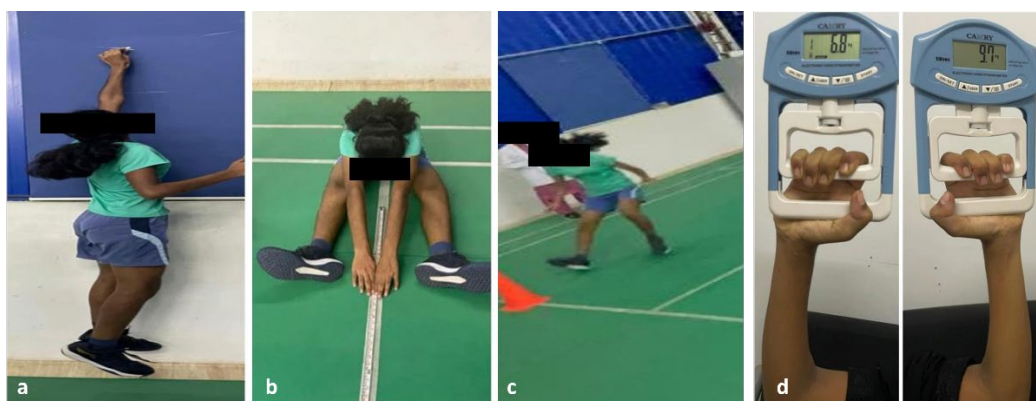


Figure 2 a. Vertical leap Test, b. Sit-and-reach, c. Agility Test and d. Grip force Test

## 2.4. Intervention Methods

### 2.4.1. Routine Tennis Training (Control and Experimental)

Both groups participated in a standardized tennis program for 90 minutes per session. This phase was structured into a 15-minute warm-up, a 60-minute main technical block, and a 15-minute cool-down. The technical block focused on stroke techniques, including high-spin forehands, backhands, and drive volleys, executed at approximately 75% intensity.

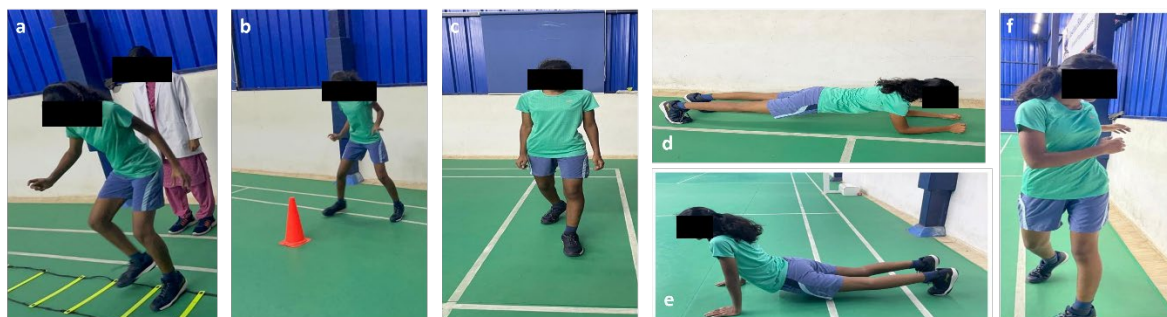
Table 1. 8-Week Routine Tennis Training Program (All Participants)

Phase	Duration	Activities
Warm-up	15 mins	Running and dynamic stretching exercises.
Main Phase (Days 1–3)	60 mins	Manual low-ball feed (100 Fh/Bh strokes); Flat feeding spinning incoming balls (100 Fh/Bh); Baseline high spin feed (100 Fh/Bh); Midi field-to-field drive volleys; Slice feeding.
Main Phase (Days 4–5)	60 mins	Rally drills on height-increased net (Cross Fh/Bh, Parallel Fh/Bh, Mixed).
Main Phase (Day 6)	60 mins	Low ball feed in front of net; drive volley training in mini field (100 Fh/Bh).
Main Phase (Days 7–8)	60 mins	Deep ball baseline exercises; within-point match monitoring.
Cool-down	15 mins	Active recovery (running) and static stretching.

### 2.4.2. Functional Training Program (Experimental Only)

The Experimental Group replaced two days of routine training with a specialized functional conditioning program. This intervention targeted the kinetic chain through multi-planar movements.

Core and Rotational Stability: Exercises included the 4-point plank with limb lifts and medicine ball torso rotations to enhance the rotational power required for tennis strokes. Plank durations were maintained at maximal durability across 3 sets, while rotations involved 10 repetitions per side.



**Figure 3 a. Agility run with ladder, b. Side to side run, c. Reverse walking, d. Plank e. Burpee and f. Torso Rotation**

Plyometric and Agility Drills: Agility ladder training (forward, lateral, and in-and-out drills) was implemented to improve footwork speed and coordination. Explosive power was targeted through burpees and forward jump squats using resistance bands (12-22 lbs). Additionally, a bungee run drill was utilized to provide resistance during court-specific sprints and recovery movements.

**Table 2. 8-Week Functional Training Program (Experimental Group)**

Movement	Dosage	Movement Description
Burpees	3 sets of 10 reps	Push-up position on Bosu ball; pulling knees to abdomen and jumping vertically.
Bungee Run	3 sets (each direction)	Sprints toward the net and corridors with waistband resistance.
Forward Jump Squat	3 sets of 10 reps	Resisted leaps forward using 12-22 lbs power bands.
Plank	3 sets (Max durability)	Core stabilization with alternating limb lifts every 15 seconds.
Torso Rotation	3 sets (10 reps per side)	Medicine ball throws mimicking stroke rotational mechanics.
Side-to-Side Run	3 sets of 5 reps	Lateral movement between conic heads; clearing tennis balls.
Agility Run	3 sets of 7 reps	Ladder drills: Frontal, lateral, and in-and-out steps.
Side-to-Side Crash	3 sets of 10 reps	Overhead medicine ball slams while standing.
Reverse Walking	3 sets of 7 reps	Hands on floor; stepping up/down the wall with feet for eccentric control.

## 3. Results

### 3.1. Baseline Demographics

Prior to the intervention, the participants' demographic and anthropometric characteristics were evaluated to ensure homogeneity between the cohorts. The mean age was  $16.2 \pm 1.1$  years for the Control Group (CG) and  $16.4 \pm 1.0$  years for the Experimental Group (EG).

**Table 3. Baseline Demographic Characteristics of Participants**

Variable	Unit	Control Group (n=10) Mean $\pm$ SD	Experimental Group (n=10) Mean $\pm$ SD	t-value	p-value
Age	years	$16.2 \pm 1.1$	$16.4 \pm 1.0$	0.42	0.67
Height	cm	$158.3 \pm 4.2$	$159.1 \pm 3.8$	0.39	0.70
Weight	kg	$52.4 \pm 5.1$	$53.0 \pm 4.7$	0.28	0.78
BMI	kg/m <sup>2</sup>	$20.9 \pm 1.8$	$21.0 \pm 1.6$	0.15	0.88
Playing Experience	months	$8.5 \pm 1.2$	$8.8 \pm 1.4$	0.51	0.62

Statistical analysis revealed no significant differences at baseline in terms of height, weight, Body Mass Index (BMI), or tennis playing experience ( $p > 0.05$ ), as shown in Table 3. This parity established a comparable starting point for evaluating the training interventions.

### 3.2. Intra-Group Biomotor Adaptations

#### 3.2.1. Control Group (Routine Training)

Analysis of the Control Group outcomes indicated that an 8-week routine tennis training program, performed in isolation, was insufficient to elicit significant statistical improvements in biomotor proficiencies. While minor numerical shifts were noted in agility ( $23.00 \pm 1.83$  s to  $19.60 \pm 1.26$  s) and grip strength ( $15.34 \pm 1.80$  kg to  $17.12 \pm 1.43$  kg), these changes failed to meet the threshold for significance ( $p > 0.05$ ), as shown in Table 4.

**Table 4. Pre- and Post-Test Comparison – Control Group**

Variable	Pre-test Mean $\pm$ SD	Post-test Mean $\pm$ SD	t-value	p-value
Agility (T-Test, s)	$23.00 \pm 1.83$	$19.60 \pm 1.26$	7.96	$>0.05$
Grip Strength (kg)	$15.34 \pm 1.80$	$17.12 \pm 1.43$	8.24	$>0.05$
Flexibility (cm)	$84.10 \pm 3.48$	$74.30 \pm 4.90$	8.16	$>0.05$
Height/Reach (cm)	$59.30 \pm 6.58$	$73.00 \pm 2.94$	8.09	$>0.05$
Vertical Jump (m)	$1.97 \pm 0.27$	$2.40 \pm 0.37$	11.72	$>0.05$

### 3.3. Experimental Group (Functional + Routine Training)

In contrast, the Experimental Group exhibited profound physiological adaptations across all measured variables ( $p < 0.0001$ ). The integration of functional training resulted in a 34.3% improvement in agility times and an 80.2% increase in hand grip strength (from  $15.6 \pm 1.45$  kg to  $28.12 \pm 2.25$  kg). Flexibility scores improved significantly from  $83.2 \pm 4.13$  cm to  $51.4 \pm 4.06$  cm. These gains reflect a robust enhancement in both muscular recruitment and movement economy (Table 5).

**Table 5. Pre- and Post-Test Comparison – Experimental Group**

Variable	Pre-test Mean $\pm$ SD	Post-test Mean $\pm$ SD	t-value	p-value
Agility (T-Test, s)	$22.7 \pm 2.21$	$14.9 \pm 0.99$	15.92	$<0.0001$
Grip Strength (kg)	$15.6 \pm 1.45$	$28.12 \pm 2.25$	37.16	$<0.0001$
Flexibility (cm)	$83.2 \pm 4.13$	$51.4 \pm 4.06$	28.05	$<0.0001$
Height/Reach (cm)	$71.0 \pm 5.54$	$92.6 \pm 2.99$	10.45	$<0.0001$
Vertical Jump (m)	$1.97 \pm 0.28$	$2.43 \pm 0.32$	17.25	$<0.0001$

### 3.4. Comparative Inter-Group Analysis

The post-intervention comparison between the CG and EG confirmed that the hybrid functional training model was markedly superior to routine training alone ( $p < 0.01$ ). Significant disparities were observed in post-test agility, grip strength, and reach metrics (Table 6). Although both groups improved their vertical jump height, the experimental group achieved a slightly higher absolute peak ( $2.43 \pm 0.32$  m) compared to the control group ( $2.40 \pm 0.37$  m), suggesting enhanced explosive power output.

**Table 6. Between-Group Post-Test Comparison**

Variable	Control Group (Post-test Mean $\pm$ SD)	Experimental Group (Post-test Mean $\pm$ SD)	t-value	p-value
Agility (s)	$19.60 \pm 1.26$	$14.90 \pm 0.99$	9.24	$<0.01$
Grip Strength (kg)	$17.12 \pm 1.43$	$28.12 \pm 2.25$	13.15	$<0.01$
Flexibility (cm)	$74.30 \pm 4.90$	$51.40 \pm 4.06$	11.38	$<0.01$
Height/Reach (cm)	$73.00 \pm 2.94$	$92.60 \pm 2.99$	14.77	$<0.01$
Vertical Jump (m)	$2.40 \pm 0.37$	$2.43 \pm 0.32$	0.19	$>0.05$

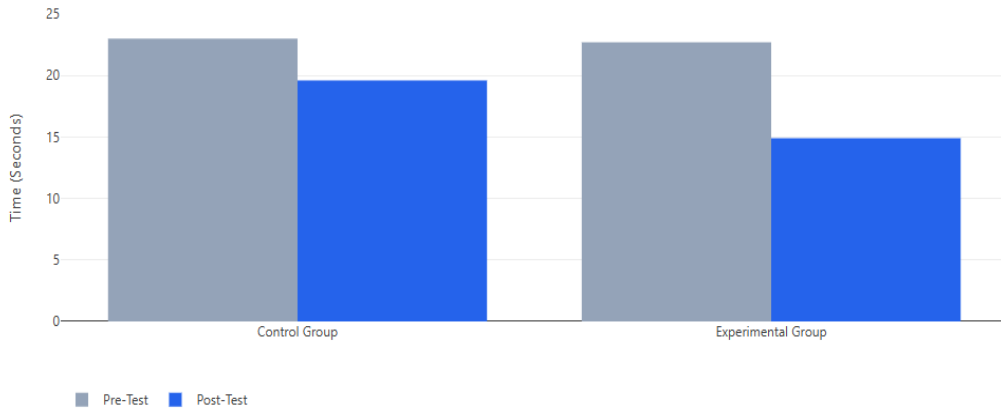


Figure 4. Impact of Functional Training on Agility (T-Test)

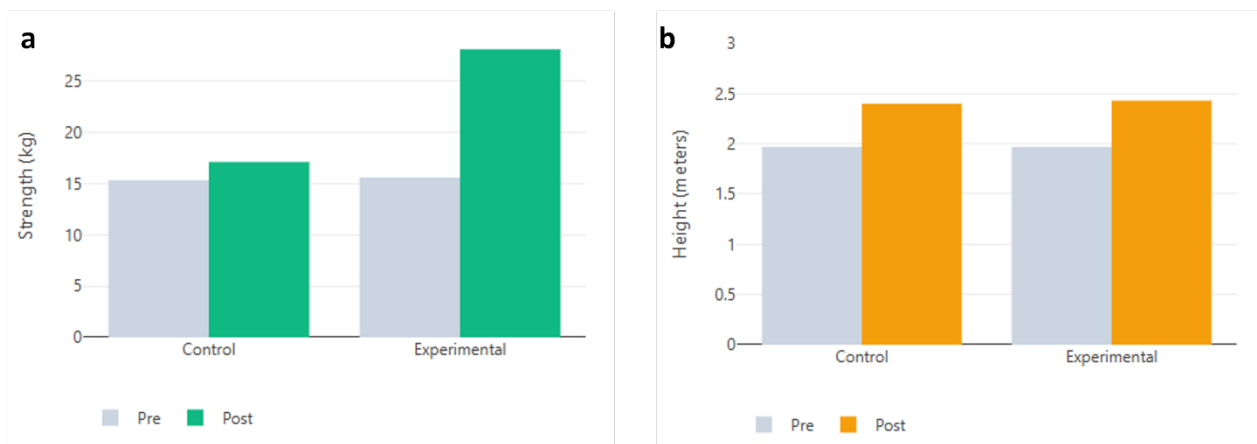


Figure 5. a. Grip Strength b. Vertical Jump Power

### 3.5. Speed and Anaerobic Power Outcomes

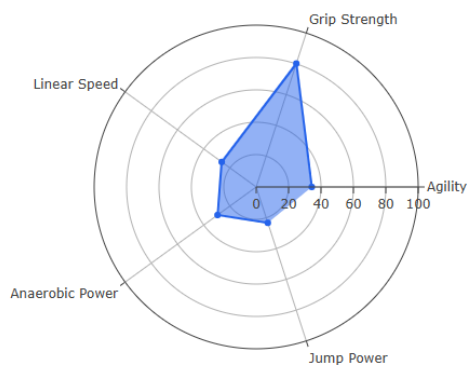
Further assessments of linear speed and anaerobic capacity showed substantial gains in the experimental cohort. Linear 10-m sprint times decreased from  $2.85 \pm 0.12$  s to  $2.10 \pm 0.08$  s ( $p < 0.0001$ ), while anaerobic hopping repetitions increased from  $112 \pm 8.4$  to  $145 \pm 9.2$  reps/60s. The control group showed no meaningful change in these performance indicators (Table 7). The overall magnitude of adaptation for the experimental group is summarized as a percentage improvement in Table 8.

Table 7. Speed and Anaerobic Power (Hopping) Performance

Group	Variable	Pre-test Mean $\pm$ SD	Post-test Mean $\pm$ SD	p-value
Experimental	10-m Sprint (s)	$2.85 \pm 0.12$	$2.10 \pm 0.08$	$<0.0001$
	Hopping (reps/60s)	$112 \pm 8.4$	$145 \pm 9.2$	$<0.0001$
Control	10-m Sprint (s)	$2.88 \pm 0.14$	$2.82 \pm 0.11$	$>0.05$
	Hopping (reps/60s)	$115 \pm 9.1$	$118 \pm 8.7$	$>0.05$

Table 8. Percentage Improvements in Biomotor Abilities (Experimental Group)

Biomotor Ability	Pre-test	Post-test	% Improvement
Agility (s)	22.7	14.9	34.3% ↓
Muscular Strength (kg)	15.6	28.12	80.2% ↑
Linear Speed (s)	2.85	2.10	26.3% ↓
Anaerobic Power (reps)	112	145	29.5% ↑
Lower Limb Power (m)	1.97	2.43	23.3% ↑



**Figure 6. Percentage Improvement**

### 3.6. Safety

Throughout the 8-week study, participant compliance remained 100%, with no dropouts reported. No major adverse events or musculoskeletal injuries occurred during the implementation of the high-intensity functional drills. Minor delayed-onset muscle soreness (DOMS) was noted in the initial two weeks of the functional intervention, which resolved without clinical management.

## 4. Discussion

The results of this study suggest that functional training is a highly effective catalyst for biomotor development in adolescent athletes. The marked disparity between the experimental and control groups underscores the limitations of purely technical training for physical optimization. The profound improvement in agility scores within the experimental group can be attributed to the multi-planar nature of the functional drills. Unlike linear sprinting, the agility ladder and side-to-side runs mimic the "open skill" nature of tennis, where players must constantly adjust their center of gravity [13, 16]. The inclusion of core-stability exercises like the plank and torso rotations likely improved the athletes' ability to stabilize the trunk during rapid directional changes, thereby reducing the "leakage" of force through the kinetic chain [10]. The significant increase in vertical jump and grip strength highlights the efficacy of combining plyometrics (burpees, jump squats) with functional movements. Functional training enhances motor unit recruitment and synchronization, which is essential for the explosive nature of the tennis serve and groundstrokes [8, 14]. While the control group practiced these strokes, they lacked the high-intensity physiological stimulus provided by the resisted bungee runs and power-band exercises, explaining their stagnant strength metrics. The improvement in sit-and-reach scores suggests that functional movements, which often involve large ranges of motion under control, contribute to dynamic flexibility. In adolescent athletes, maintaining flexibility is crucial to prevent common overuse injuries associated with the repetitive rotational stresses of tennis [7].

## 5. Conclusion

This research work provides scientific evidence that an 8-week integrative functional training program significantly outperforms traditional tennis-only training in enhancing the biomotor profile of adolescent female players. The experimental intervention yielded superior gains in agility, muscular strength, explosive power, and flexibility. These improvements suggest that focusing on movement patterns rather than isolated muscle groups facilitates better neuromuscular adaptation during the critical developmental window of adolescence. From a practical view, coaches and sports physiotherapists should consider transitioning from purely skill-based sessions to a hybrid model that incorporates functional conditioning. Such an approach not only optimizes athletic performance but also builds a more resilient physical foundation for long-term athletic development.

### Compliance with ethical standards

### Acknowledgements

The authors wish to express their gratitude to the faculty and management of Thanthai Roever College of Physiotherapy for providing the infrastructure and support required to conduct this study. We also acknowledge the contributions of the participants and their coaches, whose dedication was fundamental to the successful implementation of the training protocols.

### Conflict of interest statement

The authors declare that they have no competing interests, financial or otherwise, that could be perceived as influencing the outcomes or integrity of the research presented in this manuscript.

### Statement of ethical approval

This study involving human participants was performed in accordance with the ethical standards of the institutional research committee (Institutional Ethics Committee of Thanthai Roever College of Physiotherapy; Approval No: TRCP/IEC/2025/042) and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

### Statement of informed consent

Informed consent was obtained from all individual participants included in the study. For participants under the age of majority, informed consent was also secured from their parents or legal guardians.

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