



Effect of 6-Week Functional Training on Smash Performance and Nervous System Function in Badminton Players: A Pilot Study

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Abstract

Purpose: Biomechanical evidence indicates that enhanced coordination in the proximal-to-distal kinetic chain contributes to smash performance in badminton players. Functional training emphasizes multi-joint and multi-muscle movement patterns, which can lead to benefits in kinetic chain function. The purpose of this study was to investigate whether 6-week functional training could improve smash performance, kinetic chain coordination, and peripheral nervous system function. **Methods:** Twelve trained badminton players were recruited. The functional training program was carried out 3 days per week for 6 weeks. Participants were tested before and after the functional training. Kinematic data during the smash task were measured to quantify smash quality, skill control, and kinetic chain efficiency. Peripheral nervous system function was assessed using patellar tendon reflex task. **Results:** We observed that participants presented greater maximum shoulder internal rotation ($p = 0.022$) and abduction ($p = 0.038$) angular velocity, as well as shorter time difference in time to peak resultant velocity between anterior superior iliac spine and acromion ($p = 0.015$) in post-compared to pre-functional training during the smash task. In addition, participants showed shorter latency in muscle response of rectus femoris ($p = 0.004$) and vastus medialis ($p = 0.031$) during the patellar tendon reflex task. **Conclusions:** These observations suggest that functional training has promise for improving coordination of the proximal-to-distal kinetic chain and optimizing peripheral nervous system function in badminton players.

Subject Areas

Sports Science

Keywords

Badminton Smash, Skill Control, Kinetic Chain, Motor-Unit Synchronization

1. Introduction

In competitive badminton athletics, the ability to hit a decisive “done deal” stroke distinguishes champions from their competitors. Among the many strokes in badminton, the smash is the most important offensive technique for finishing a competition [1] [2], as the shuttlecock can reach an incredibly high speed (>300 km/h) and a steep downward angle toward opponents [2] [3]. Consequently, it offers opponents with short reaction and movement times to return the shuttlecock. One way to optimize smash techniques is through participation in an appropriate physical training program. However, a recent systematic review with meta-analysis indicated that only one study had investigated the effects of a physical training program on smash performance [4]. This study reported that core stability training improves smash velocity and accuracy [5]. Apparently, there is lack of scientific knowledge to provide insight into developing appropriate physical training programs.

A body of biomechanical evidence suggests that increases in both linear and angular velocity of distal end-segments are associated with improved smash performance, due to enhanced transfer of linear/angular momentum to the shuttlecock [2] [3] [6]. In other words, these studies underscored the importance of the proximal-to-distal kinetic chain in generating and storing momentum to produce a more effective whip-like action at the distal end-segments [2] [3] [6]. For example, prior studies demonstrated that the distal-to-proximal force transmission order (wrist-elbow-shoulder: 27%, 9%, and 7%) [7] produces lower contributions to racket head speed than the proximal-to-distal order (shoulder-forearm-wrist: 66%, 17%, and 11%) during the badminton smash [8]. Another study reported that skilled players present a 60.2% increase in maximum shuttlecock speed compared to novice players during the badminton smash [9]. The authors interpreted these findings based on biomechanical evidence, suggesting the rapid trunk and shoulder rotations in early whip-like control induce passive elbow flexion and wrist hyperextension in skilled players [9]. Furthermore, coordination in the proximal-to-distal kinetic chain relies on the nervous system, particularly at the peripheral level [10] [11]. Thus, the physical training programs should concentrate on improving the proximal-to-distal kinetic chain and peripheral nervous system functions simultaneously.

Functional training emphasizes multi-joint and multi-muscle movement patterns rather than isolating single muscles [12] [13]. This holistic approach aims to

enhance individuals' speed, muscular strength, power, agility, balance, and coordination in ways that more closely resemble the actions required in sport and daily life [13]-[16]. Scientific evidence suggests that at least a 5-week functional training program could lead to meaningful improvement in physical functions in both athletic and non-athletic populations [14] [17] [18]. Furthermore, such training is designed to target the human kinetic chain, as it engages acceleration, deceleration, and stability across multiple joints and planes [19] [20]. Researchers also suggest that the nervous system can participate in the regulation of complex kinetic chains, thereby promoting the overall function of the neuromuscular system [18]. Consequently, functional training has promise for improving smash performance by enhancing the efficiency of proximal-to-distal kinetic chain and nervous system function in badminton players.

The purpose of this study was to investigate whether 6-week functional training could improve smash performance, kinetic chain coordination, and peripheral nervous system function. To achieve this goal, our participants performed smash and patellar tendon reflex tasks. We hypothesized that our participants would present better smash quality by enhancing maximum shuttlecock velocity and flight angle as well as decreasing past-net height, better skill control by increasing the maximum upper extremity's angular velocity and range of motion (ROM), more efficiency kinetic chain by improving coordination of proximal-to-distal joints, and better peripheral nervous system function by decreasing the latency of muscle response and increasing the muscular peak-to-peak magnitude in post-compared to pre-functional training.

2. Materials and Methods

2.1. Participants

A power analysis was conducted to determine the sample size using G*Power 3.1. According to a systematic review with meta-analysis, the positive effects of functional training on physical fitness (e.g., strength, power, endurance, and agility) in healthy individuals presented large effect size ranging from 1.32 to 3.09 [21]. Thus, the minimum sample size was calculated to be 8 participants using a one-tailed t-test (effect size = 1.0, power = 80%, and α level = 0.05). Given an estimated 70% retention rate, we recruited 12 trained college badminton players in this study. The inclusion criteria were 1) at least 3 years of badminton training experience; 2) no history of musculoskeletal injury in the past 6 months; 3) no history of neurological disease; and 4) no drug and alcohol abuse. All participants provided informed consent before data collection. In addition, this study was approved by the Research Ethics Board of Jimei University (No. 20250524889).

2.2. Procedures

We conducted a one-group pre-post study design. Thus, participants visited the laboratory twice and followed the same experimental protocols under the same testing conditions before and after functional training program. Specifically, participants

completed a 6-week functional training program on Mondays, Wednesdays, and Fridays from 5 to 5:45 pm. Each training included a 5-minute standardized warm-up, 25-minute functional training, and 15-minute standardized cool-down. The detailed functional training schedule was described in **Table 1**. Participants were considered withdrawn from this study after three absences. To ensure objective assessment, metric data was measured using state-of-the-art instruments.

Table 1. Detailed schedule for the functional training program.

Warm Up (5 mins)	
Jog: 60 s	
Squat jumps + Plank + Supine hip thrust: 2 × 6 reps + 40 s + 6 reps	
Bear crawl: 2 × 15 m	
Quick Feet: 2 × 10 reps	
Shoulder stretch + Calf raises + World's greatest stretch	
Week 1	
Session 1 (15 mins)	Session 2 (10 mins)
Single-leg contralateral anterior reach: 3 × 6 reps	Stability ball log roll: 3 × 10 reps
Single-leg squat: 3 × 6 reps	BP pulsating backswing: 3 × 10 reps
Double-leg squat: 3 × 6 reps	BP short-rotation exercise: 3 × 10 reps
Alternating lunges: 3 × 6 reps	
Week 2	
Session 1 (15 mins)	Session 2 (10 mins)
Medical ball woodchops: 3 × 8 reps	Triple threat: 3 × 45 s
Battling ropes alternating waves: 3 × 60 s	Side plank T: 3 × 120 s
Medicine ball rotational lunge: 3 × 15 reps	Stability ball hip lifts: 3 × 15 reps
Band core rotations: 3 × 8 reps	BP push-pull: 3 × 15 reps
Week 3	
Session 1 (15 mins)	Session 2 (10 mins)
One kettlebell single-leg deadlift: 3 × 30 s	Kettlebell forward lunge: 3 × 12 reps
BP staggered-stance contralateral with banded pull down: 3 × 10 reps	Alternating split jumps: 3 × 120 s
Single-arm staggered-stance row with kettlebell: 3 × 12 reps	Medical ball overhead slam: 3 × 15 reps
X raise: 4 × 12 reps	Medical ball overhead side slam: 3 × 15 reps
Week 4	
Session 1 (15 mins)	Session 2 (10 mins)
Diagonal low hurdle jumps: 4 × 120 s	Single-arm kettlebell swing: 3 × 15 reps
Low hurdle running: 4 × 120 s	Kettlebell lateral lunge: 3 × 15 reps
Agility ladder lateral jump: 4 × 60 s	BP low-to-high chop: 3 × 15 reps
Banded side shuffle: 2 × 60 s	Single-arm staggered-stance row with kettlebell: 3 × 15 reps
Week 5	
Session 1 (15 mins)	Session 2 (10 mins)
Medical ball woodchops: 3 × 8 reps	Medical ball woodchops: 3 × 8 reps
Side plank T: 3 × 120 s	Butterfly elastic band exercise: 3 × 10 reps
Medicine Ball Squat: 3 × 8 reps	Bird dog exercise: 3 × 60 s
Banded side shuffle: 2 × 60 s	Medicine ball rotational lunge: 3 × 12 reps

Continued

Week 6	
Session 1 (15 mins)	Session 2 (10 mins)
Single-arm kettlebell swing: 6 × 8 reps	Backward medicine ball throw: 3 × 8 reps
BP push-pull: 6 × 8 reps	Medical ball overhead side slam: 3 × 12 reps
BP deadlift: 6 × 8 reps	Staggered-stance alternating row with kettlebell: 3 × 15 reps
Single-arm dumbbell fly: 6 × 8 reps	Burpee: 3 × 15 reps
Cool Down (15 mins)	
Full-body stretching	
Using a foam roller for muscle tension release at gluteus, quadriceps, and back and should muscles	

To evaluate changes in smash quality, skill control, and kinetic chain coordination, three-dimensional kinematic data were collected by a 16-camera three-dimensional motion capture system (Vantage 8, Vicon, Oxford, UK) at a sampling rate of 200 Hz during the badminton smash task. Prior to data collection, twenty (diameter: 14-mm) reflective markers were attached to participant's upper bodies. These markers were placed on the left/right anterior superior iliac spine, left/right posterior superior iliac spine, left/right acromion, left/right lateral epicondyle of humerus, left/right medial epicondyle of humerus, left/right radius-styloid process, left/right ulna-styloid process, left/right head of second metacarpal, seventh cervical vertebrae, tenth thoracic vertebrae, sternum xiphisternal joint, and sternum jugular notch. Additionally, seven reflective markers (at the 2, 4, 6, 8, 10, 12 o'clock positions on the racket face and the midline of the racket handle) were placed on the badminton racket (Astrox-99, YONEX Ltd., Tokyo, Japan); one reflective marker was placed on the head of shuttlecock (AS-05, YONEX Ltd., Tokyo, Japan); and two reflective markers were placed at the 1/3 and 2/3 positions on the net's white band. The net height was 1.55 meters. The smash task required a fixed lower-extremity posture. Participants stood with their supporting leg at the midpoint of the midpoint of the badminton court's midline on one side, using their habitual preparatory posture. This position was marked as a guide to participants. Our server stood at the same position on the opposite side of the court. To maintain consistent service quality, a 4-m-high line parallel to the short service line was established; the shuttlecock had to just past this line to qualify as a valid serve. Participants practiced several times to familiarize themselves with the setup. During data collection, the cue "ready" signaled participants and the server to get set, and the cue "go" signaled the serve and smash preparation. Three valid trials were collected that met the following criteria: 1) qualified service, 2) supporting leg remaining in the marked position after the smash, 3) no reported discomfort during the smash, and 4) all reflective markers recorded.

To evaluate changes in peripheral nervous system function, we conducted a patellar tendon reflex task. The reason to use this test is that the nervous system can participate in the regulation of complex kinetic chains from distal to proximal segments [18]. To standardize strike intensity, a custom device was constructed consisting of two adjustable tripods, a rigid beam, a bearing, and a rubber hammer

(**Figure 1**). The rubber hammer's range of motion was fixed between the 2 (60°) and 9 (270°) o'clock positions. In addition, an electromyograph (EMG) system (ME6000, Mega Electronics Ltd., Kuopio, Finland) was used to measure muscle activity in rectus femoris, vastus lateralis, and vastus medialis at a sampling rate of 1000 Hz. Prior to data collection, surface bipolar (20-mm interelectrode distance) Ag/AgCl gel electrodes (square shaped with a 1 cm² surface area) were attached to the targeted muscles according to SENIAM guidelines. Then, participants sat in an armless chair, holding the sides, leaning against the chair back, and maintaining 90° angles between adjacent body segments with eyes closed. Our investigator attached a force sensor (SBT640, Simbatouch Ltd., Guangdong, China), sampling rate of 1000 Hz, to the top of patellar tendon and adjusted the custom device to fully strike the force sensor. The force sensor was synchronized with the EMG system. During data collection, the cue "ready" instructed participants to remain relaxed, and the cue "go" instructed the investigator to release the hammer from the 2 o'clock position. Three valid trials were collected that met the following criteria: 1) sitting still and relaxing before the strike; 2) only the target shank kicking out after the strike; 3) eyes remaining closed; and 4) signals of good quality.

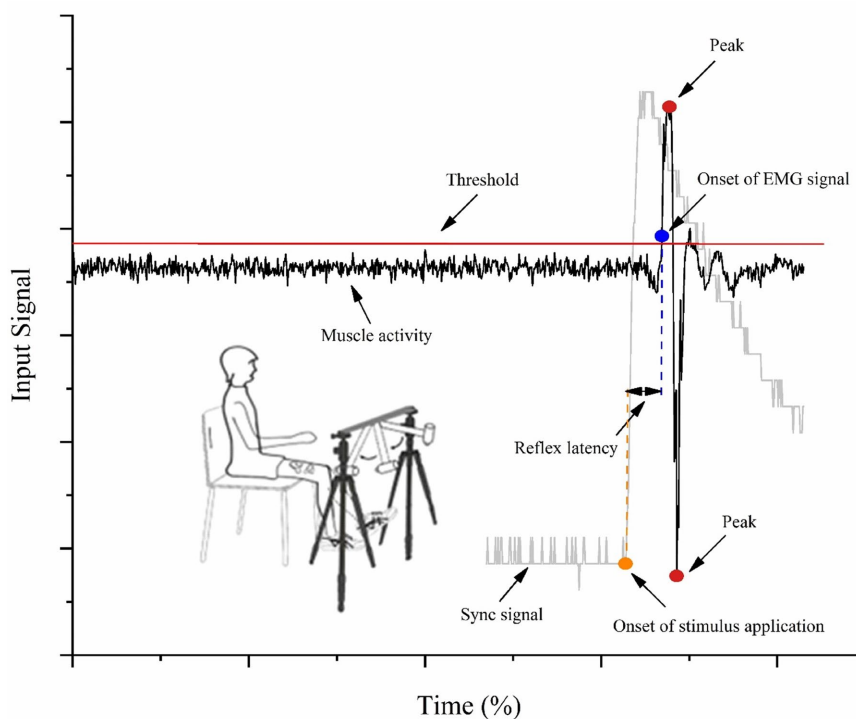


Figure 1. Illustration of the patellar tendon reflex task.

2.3. Data Analysis

Marker trajectory gap-filling was processed using Nexus software (Vicon, Oxford, UK) and exported for future analysis in Visual3D (Has Motion, Ontario, Canada). First, we built an 8-segment 6-degree-of-freedom upper body mode. These markers also enabled modeling of the badminton racket, shuttlecock, and net. Then,

kinematic data was filtered with a low-pass, zero-lag, fourth-order Butterworth filter with cutoff frequency of 10 Hz [22].

Smash quality was evaluated by calculating maximum shuttlecock velocity, past-net height, and shuttlecock flight angle [9]. Shuttlecock velocity was calculated as the resultant velocity of the marker on the shuttlecock using the central difference method. Past-net height was determined as the difference between net height and the Z-axis height at which the shuttlecock first passed above the net. To determine shuttlecock flight angle, the Euclidean distance (Y-Z plane) from the shuttlecock marker at impact to its position when first passing above the net was calculated, along with the straight-line distance (Y- and Z-axes) between the shuttlecock marker at impact and the midpoint of the two markers on the net's white band. The shuttlecock flight angle was then calculated using the law of cosines. Greater magnitudes of maximum shuttlecock velocity and flight angle, and a smaller magnitude of past-net height, reflected better smash quality. The event was defined from shuttlecock impact to initial passage over the net [2].

Skill control was evaluated by calculating the angle and angular velocities in the shoulder, elbow, and wrist joints at dominant side, defined as the orientation of the distal segment relative to the proximal segment [9]. In addition, the X factor was calculated as the planar angle in the transverse plane using a four-point approach (right and left shoulder and hip joint centers) [9]. The velocity of the badminton racket's center of mass was also calculated using the central difference method. The following were selected as dependent variables: maximum shoulder joint angular velocity and its ROM in the sagittal (extension/flexion), frontal (abduction/adduction), and transverse (internal/external rotation) planes; maximum elbow and wrist joint angular velocities and their sagittal ROMs; X factor ROM; and maximum badminton racket velocity in the sagittal plane. Greater magnitudes reflected better skill control. The event was defined from the center of mass reaching its lowest point to shuttlecock impact [2].

Kinetic chain coordination was evaluated by calculating the resultant velocities of markers at the anterior superior iliac spine, acromion, lateral humeral epicondyle, radial styloid process, and 12 o'clock position on the racket face. The time differences to peak velocity between adjacent markers from proximal to distal, as well as between the 12 o'clock racket-face marker and impact time, were then computed. Less negative/positive time differences reflected better kinetic chain coordination. The event was defined from the center of mass reaching its lowest point to initial shuttlecock passage over the net [2].

Raw EMG signals were saved as ASCII files for processing in MATLAB (R2023a, MathWorks, Natick, MA, USA). To detect onsets, baseline shifts in raw EMG signals were removed using detrended fluctuation analysis. The mean and standard deviation of EMG amplitude were then calculated over 500 ms prior to stimulus application [23]. Stimulus onset was defined as the first significant deflection in the synchronization signal. A threshold line was set at 2.5 standard deviations above the mean EMG baseline amplitude [24]. EMG onset was defined as the first significant deflection exceeding this threshold. Thus, reflex latency was

calculated as the time from stimulus onset to EMG onset for each target muscle (**Figure 1**). Furthermore, peak-to-peak magnitude of muscle activity during the patellar tendon reflex was calculated. Shorter reflex latencies and greater peak-to-peak magnitudes reflected better peripheral nervous system function.

2.4. Statistical Analysis

Shapiro-Wilk tests were used to assess normality of each dependent variable ($\alpha = 0.05$). If a dependent variable showed a non-normal distribution, Wilcoxon signed-rank tests were used to determine significant differences in smash and patellar tendon reflex measures. For normally distributed data, paired t-tests were performed to determine the effects of functional training on each dependent variable. Cohen's *d* effect sizes were calculated for post hoc comparisons, where $0.20 \leq d \leq 0.49$ indicated a small effect, $0.50 \leq d \leq 0.80$ indicated a medium effect, and $d > 0.80$ indicated a large effect. All analyses were conducted using SPSS (version 26.0, IBM Corp., Armonk, NY, USA). The significance level was set at $\alpha = 0.05$.

3. Results

All participants ($N = 12$, 1 female, 1 left dominant, mass = 70.33 ± 5.57 kg, height = 178.42 ± 3.99 cm, and trained year = 6.42 ± 2.94 years) completed the functional training program. Means and standard deviations for each dependent variable are presented in **Table 2**.

Table 2. Mean and standard deviation of each dependent variable in pre-and post-functional training during the smash, the patellar tendon reflex, and reaction time tasks.

Variables	Pre-test	Post-test	<i>p</i> -value
Shuttlecock velocity (m/s)	50.17 ± 3.20	50.18 ± 2.99	0.986
Flight angle (deg)	15.32 ± 2.13	14.13 ± 1.88	0.212
Past-net height (m)	0.20 ± 0.13	0.19 ± 0.080	0.807
Wrist flexion angular velocity (°/s)	1118.26 ± 141.41	1146.17 ± 144.45	0.573
Elbow extension angular velocity (°/s)	1346.39 ± 326.14	1470.12 ± 224.88	0.142
Shoulder flexion angular velocity (°/s)	235.03 ± 97.47	207.70 ± 64.13	0.109
Shoulder abduction angular velocity (°/s)	461.66 ± 115.38	515.94 ± 112.32	0.038*
Shoulder internal rotation angular velocity (°/s)	1487.83 ± 265.93	1648.58 ± 232.64	0.022*
Racket flexion velocity (m/s)	22.28 ± 1.53	22.60 ± 1.39	0.566
Wrist sagittal ROM (°)	59.22 ± 14.04	62.88 ± 10.76	0.153
Elbow sagittal ROM (°)	98.57 ± 16.47	104.12 ± 10.16	0.367
Shoulder sagittal ROM (°)	88.85 ± 25.38	98.41 ± 14.28	0.132
Shoulder frontal ROM (°)	84.71 ± 19.58	89.76 ± 17.17	0.118
Shoulder transverse ROM (°)	124.21 ± 14.77	131.76 ± 13.88	0.236
X factor ROM (°)	31.95 ± 14.67	27.69 ± 8.63	0.199

Continued

RASI-RSHO (s)	-0.14 ± 0.032	-0.11 ± 0.016	0.015*
RSHO-RELB (s)	0.024 ± 0.033	0.0071 ± 0.0091	0.080
RELB-RWRA (s)	-0.056 ± 0.0052	-0.055 ± 0.0066	0.355
RWRA-R1 (s)	-0.023 ± 0.0025	-0.024 ± 0.0045	0.479
Latency of Rectus femoris (ms)	84.66 ± 15.53	66.58 ± 11.49	0.004*
Latency of Vastus lateralis (ms)	85.23 ± 17.37	74.69 ± 12.95	0.094
Latency of Vastus medialis (ms)	79.02 ± 14.02	65.66 ± 9.78	0.031*
Peak-to-peak magnitude of Rectus femoris (mv)	1.79 ± 1.56	2.80 ± 2.34	0.190
Peak-to-peak magnitude of Vastus lateralis (mv)	2.56 ± 2.18	3.79 ± 3.05	0.098
Peak-to-peak magnitude of Vastus medialis (mv)	3.33 ± 2.49	4.59 ± 3.75	0.162

ROM means range of motion; the measures related to angular velocity are maximum value; RASI-RSHO means time difference in time to peak resultant velocity between anterior superior iliac spine and acromion; RSHO-RELB means time difference in time to peak resultant velocity between acromion lateral epicondyle of humerus, RELB-RWRA means time difference in time to peak resultant velocity between lateral epicondyle of humerus and radius-styloid process; and RWRA-R1 means time difference in time to peak resultant velocity between radius-styloid process and 12 o'clock of racket face. Asterisk indicates significant statistical difference.

The functional training program improved skill control and kinetic chain coordination in participants but did not enhance smash quality. Specifically, participants presented 10.80% greater maximum shoulder internal rotation angular velocity ($p = 0.022$ & $d = 0.64$; **Table 2**) and 11.76% greater maximum shoulder abduction angular velocity ($p = 0.038$ & $d = 0.48$; **Table 2**) in post-compared to pre-functional training during the smash. In addition, the time difference to peak resultant velocity between the anterior superior iliac spine and acromion was 18.19% shorter in post-compared to pre-functional training during the smash ($p = 0.015$ & $d = 1.00$; **Figure 2** & **Table 2**). A trend toward significance was observed in the time difference to peak resultant velocity between the acromion and lateral humeral epicondyle, which was 70.78% shorter in post-compared to pre-functional training ($p = 0.080$ & $d = 0.72$; **Table 2**).

The functional training program also enhanced peripheral nervous system function in participants. Specifically, participants showed 21.36% shorter muscle response latency in the rectus femoris ($p = 0.004$ & $d = 1.32$; **Figure 3** & **Table 2**) and 16.90% shorter latency in the vastus medialis ($p = 0.031$ & $d = 1.11$; **Figure 3** & **Table 2**) in post-compared to pre-functional training during the patellar tendon reflex task (**Figure 3**). Additionally, trends toward significance were observed in vastus lateralis muscle response latency ($p = 0.094$, $d = 0.69$) and peak-to-peak magnitude ($p = 0.098$, $d = 0.47$), showing 12.37% shorter latency and 48.31% greater peak-to-peak magnitude in post-compared to pre-functional training.

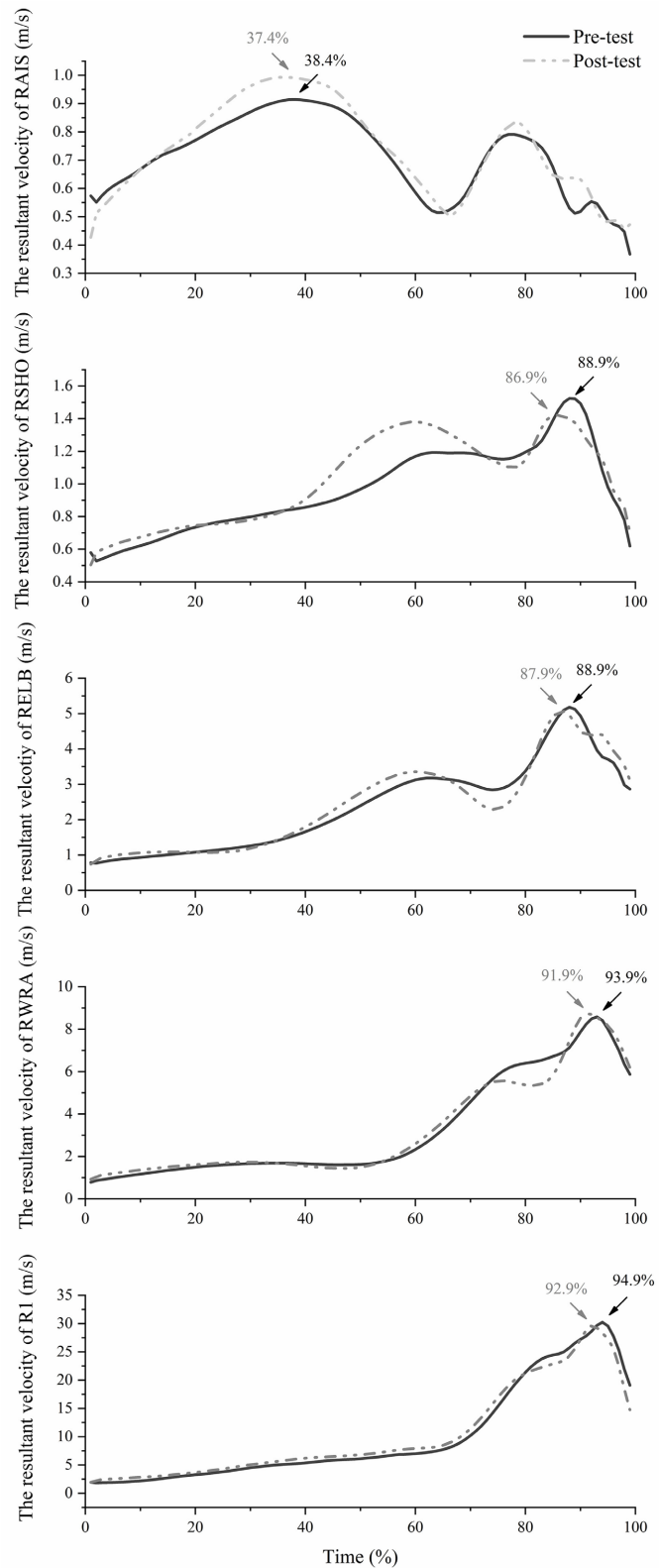


Figure 2. Illustration of proximal-to-distal kinetic chain according to the resultant velocity from the markers at different body segments. RASI means superior iliac spine and acromion; RSHO means acromion; RELB means lateral epicondyle of humerus; RWRA means radius-styloid process; and R1 means 12 o'clock of racket face.

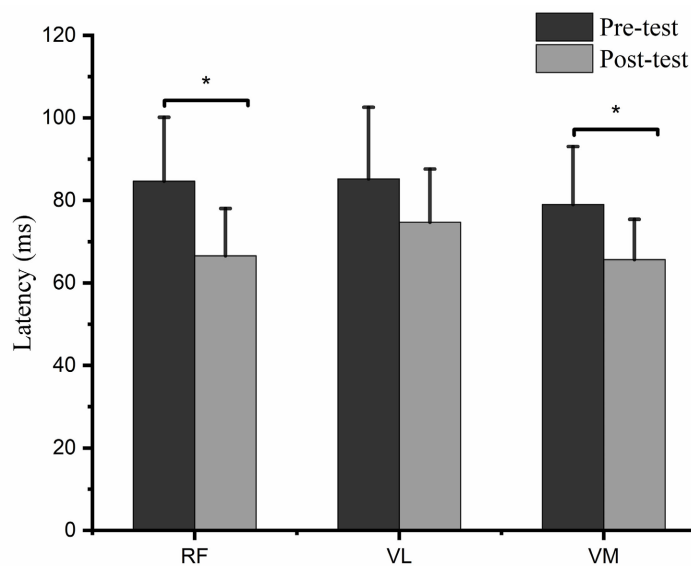


Figure 3. The latency of muscle response in rectus femoris (RF), vastus lateralis (VL), and vastus medialis (VM) between pre- and post-test during the patellar tendon reflex task.

4. Discussion

The purpose of the current study was to investigate the effect of 6-week functional training on smash performance, kinetic chain coordination, and peripheral nervous system function in badminton players. The results showed that functional training contributed to better shoulder joint skill control and upper-extremity proximal-to-distal kinetic chain coordination during the smash task, as well as shorter muscle response latencies in rectus femoris and vastus medialis during the patellar tendon reflex task. However, functional training did not enhance smash quality or skill control in the elbow and wrist joints. Thus, these observations partially support our hypothesis.

The functional training program appeared to facilitate shoulder joint skill control, leading to enhanced maximum shoulder abduction and internal rotation angular velocities during the smash. Prior studies indicated that enhanced shuttlecock velocity is associated with a shorter acceleration phase duration and greater shoulder internal/external rotation angle at impact during the smash [3] [25]. Consequently, greater shoulder internal rotation angular velocity should result in greater shuttlecock velocity. However, the increased maximum shoulder abduction angular velocity may have counterbalanced the benefits of increased internal rotation angular velocity, resulting in no significant difference in maximum shuttlecock velocity at post-functional training. A correlational analysis also indicated that faster shuttlecock velocity is associated with a less elevated shoulder position at impact, which would lead to smaller shoulder abduction angular velocity [25]. Additionally, faster shuttlecock velocity was highly associated with greater maximum wrist flexion velocity and a more negative X factor at the end of retraction [3]. Our study did not observe significant changes in these related measures after functional training. Another possible explanation is the strict lower-extremity

posture requirements during the smash task, which may have constrained upper-extremity skill control. Thus, future studies should investigate the effects of functional training on smash quality and skill control during the jump smash.

In addition, the functional training program improved coordination of the proximal-to-distal kinetic chain, which may lead to reduced mechanical energy cost and injury risk during the smash [10] [26] [27]. Kinetic chain inefficiency occurs when there is a defect at any segment within the chain, which affects energy or force transfer to adjacent segments [10] [26] [27]. This is because the kinetic chain involves sequential activation of proximal-to-distal segments, enabling efficient generation, summation, and transfer of mechanical energy to produce a more effective whip-like action at distal end-segments during the smash [9]. Better kinetic chain coordination means that distal segment motion begins as the proximal segment reaches maximum velocity [9]. Our study supports this, as the time difference to peak resultant velocity between the anterior superior iliac spine and acromion decreased from 0.14 s to 0.11 s in pre-compared to post-functional training. Furthermore, we also observed that the time difference in time to peak resultant velocity between the acromion and lateral humeral epicondyle showed nearly zero delay (0.0071 s) after functional training. However, the improvement in kinetic chain after functional training failed to produce a greater maximum wrist flexion velocity. Therefore, this improvement could be very limited in contributing to smash quality.

Although this study did not provide direct evidence explaining the positive changes in kinetic chain coordination, a review suggested that the nervous system participates in regulating complex kinetic chains [10]. Our patellar tendon reflex task indicated that participants presented shorter latency in muscle response of rectus femoris and vastus medialis, suggesting a faster nerve conduction velocity [28]. Moreover, the vastus medialis (79.02 ms) was activated before with the simultaneously activated vastus lateralis (85.23 ms) and rectus femoris (84.66 ms) during the pre-test. Interestingly, the vastus medialis (65.66 ms) and rectus femoris (66.58 ms) were simultaneously activated and they were activated before with the vastus lateralis (74.69 ms) during the post-test. These observations suggest that functional training induced changes in motor-unit synchronization among the quadriceps muscles, leading to more efficient muscle contractions and faster knee extension [29]. Collectively, these neural efficiencies could improve kinetic chain control and coordination [10]. Due to instrument limitations, we could not perform a more appropriate H-reflex test on upper-extremity muscles to interpret the effects of functional training on nervous system function. Thus, future studies should address this.

Finally, the functional training program did not appear to improve smash quality from an accurate perspective (e.g., fight angle and past-net height). Experimental evidence has demonstrated that smash accuracy is associated with control of distal muscles, such as the flexor carpi ulnaris and extensor carpi radialis [30]. In addition, greater wrist sagittal ROM during the smash can lead to a greater

flight angle and lower past-net height [9]. However, our study did not observe a significant difference in wrist-related measures. Additionally, previous studies reported that skilled player present a flight angle of approximately 14.8° and past-net height of 0.20 m during the smash [2] [9]. A possible interpretation is that our participants are skilled badminton players with 3 to 10 years of training. Thus, they presented very difficult to improve the smash accuracy with the pretty good performance during the pre-test. Future studies should investigate the effects of functional training on smash performance in novice badminton players.

This study has several limitations that should be acknowledged. First, the one-group pre-post design lacks a control group, which limits the ability to draw causal effects regarding the effectiveness of the functional training. The observed improvements may have been influenced by factors such as maturation, testing familiarity, or external events rather than the intervention itself. Second, the relatively small sample size reduces the statistical power and generalizability of our findings. Also, the sample size calculation is based on a meta-analysis of functional training's effect on general physical fitness in healthy individuals, which may not be specific to the highly specialized biomechanical and neuromuscular variables measured in this study. Third, the shuttlecock was served manually rather than by a machine, which may have introduced variability in the shuttle trajectory and speed, potentially affecting the consistency of the participants' responses. Fourth, the smash task required a fixed lower-extremity posture, which constraint may have limited the transfer of force and influenced the upper-extremity kinematic features. Therefore, the overall strength of the findings was considered very low in this study.

5. Conclusion

The present study demonstrates that a 6-week functional training program can enhance shoulder joint control, improve proximal-to-distal kinetic chain coordination, and shorten muscle response latency in badminton players, suggesting better neuromuscular efficiency and energy transfer during the smash. For coaches and practitioners, integrating functional training into regular practice may strengthen linkages among body segments, helping badminton players generate force more efficiently and reduce injury risk. Moreover, the shorter muscle response latencies suggest improvement in motor-unit synchronization, faster nerve conduction velocity, and more efficient muscle contractions, which may underline improvements in proximal-to-distal kinetic chain coordination after function training.

Conflicts of Interest

There are no competing interests to report.

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