



OPEN Similar adaptive responses in the upper body physical performance of table tennis players following the traditional and cluster set resistance and plyometric training

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Numerous studies have investigated the impact of resistance training (RT) and plyometric training (PT) set configurations (cluster sets [CS] and traditional sets [TS]) on lower body performance adaptations. However, the effects of these training modalities on upper body physical performance, particularly among Table Tennis (TT) players, remain unclear. Therefore, this study aimed to examine the effects of an 8-week RT and PT using CS and TS configurations on the physical performance attributes of male TT players. Forty young male players were recruited from a local academy and after determining their dominant hand, divided into CS-PT, TS-PT, CS-RT, TS-RT, and active control (CON) groups, each of eight. Pre- and post-interventions, the upper body muscular power (medicine ball throw), maximal strength (bench press), reaction time, and arm crank anaerobic power test were measured. Following the intervention, the CON group exhibited no changes; however, the CS-PT, TS-PT, CS-RT, and TS-RT groups displayed significant ($p = 0.001$) improvements in muscular power (effect size [ES] = 1.21 [large], 1.02 [medium], 0.81 [medium], 0.64 [medium]), strength (ES = 0.40 [small], 0.43 [small], 0.62 [medium], 0.63 [medium]), reaction time (ES = -0.71 [medium], -0.68 [medium], -0.83 [medium], -0.61 [medium]), peak power (ES = 1.83 [large], 1.66 [large], 0.90 [medium], 0.67 [medium]), and mean power (ES = 0.89 [medium], 0.89 [medium], 0.57 [small], 0.59 [small]), respectively. The PT groups indicated significantly greater changes than the RT groups in both muscular (CS, $p = 0.021$; TS, $p = 0.018$) and anaerobic power (peak power: CS, $p = 0.017$; TS, $p = 0.011$; mean power: CS, $p = 0.024$; TS, $p = 0.042$) performance, while the RT groups showed greater adaptive responses than the PT groups in maximal strength (CS, $p = 0.033$; TS, $p = 0.048$). In conclusion, PT is recommended for enhancing power performance, while RT is preferred for increasing strength. When various set configurations were incorporated, no further effects were noted.

Keywords Strength training, Explosive power, Inter-set rest, Anaerobic power

Table tennis (TT) is a dynamic sport that requires players to demonstrate swift movements, quick reflexes, and sharp visual acuity^{1,2}. The ball's velocity in this sport can peak at 200 km per hour, underscoring the importance of players' remarkable arm speed, strength, power, and rapid reaction times⁶. Beyond technical and tactical skills that are the most crucial determinants of TT performance¹, physical attributes such as maximum force, speed, acceleration, and power stand as foundational physical components influencing TT performance^{4,5}. These key aspects empower players to execute vigorous muscle contractions and effectively engage in various tasks, such as rallying with opponents⁶. As a result, the pathways of anaerobic glycolysis and ATP-PCr are crucial for short-duration maximal efforts, alongside the aerobic system which is important for recovery in TT athletes^{3,7}.

Different training techniques were employed to enhance players' strength, muscular power, and anaerobic power output^{8,9}. It seems that integrating resistance (RT) and plyometric training (PT) proves to be an efficient method for boosting these physical fitness aspects in both the upper and lower body of TT players^{6,10-14}. Numerous strength and conditioning professionals and athletes incorporate RT and PT into their training

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programs to enhance the physical fitness performance of both the upper and lower body; however, RT and PT have differences in their approaches to developing power, muscular strength, and hypertrophy^{15,16}. RT focuses on slow and controlled movements, while PT involves explosive and ballistic movements that effectively increase power performance^{6,10,12,16}.

Given the reliance of RT and PT programs on anaerobic glycolysis and ATP-PCr pathways, performing repeated repetitions in a training set can deplete glycogen and high-energy phosphates^{15–17}. This depletion leads to fatigue and decreased tension per cross-sectional area of muscle fibers, ultimately affecting physical performance¹⁸. To address this issue, adjusting rest intervals between and within sets is a recommended strategy¹⁹. In fact, a cluster set (CS) configuration of rest intervals has been suggested as a way to enhance the restoration of the metabolic and excitatory cellular environment during RT and PT sessions, leading to better fatigue management^{20–22}. This configuration involves a higher number of shorter rest periods between repetitions or sets but with a similar total training session duration compared to a traditional set (TS) distribution²³. By allowing a reduced number of repetitions per set, the CS configuration enables greater muscle power generation with each repetition²². In fact, it has been found that this configuration leads to improvements in peak power output, barbell velocity, and displacement compared to the TS configuration²⁴. These improvements are believed to be a result of the role played by short rest periods between clusters, which allow for metabolic recovery and subsequently enhance kinematics and kinetics in the later repetitions of the set when compared to TS²⁵.

To the best of our knowledge, a considerable number of studies have been conducted to investigate the effects of lower body RT and PT using CS or TS methods^{20–25}. These studies have consistently shown that CS is suitable for enhancing power performance following RT and PT^{20,22}. However, when it comes to strength gains, the findings are inconclusive and some studies have suggested that TS is more effective than CS²⁶, while others have reported conflicting results²³. Nevertheless, there is currently no available documentation specifically addressing the use of CS for RT or PT in TT players, particularly in relation to upper body strength and power performance. Therefore, the main objective of this investigation was to assess the impact of 8 weeks of RT and PT with different set configurations (CS vs. TS) on upper body reaction time, maximal strength, muscular power, and anaerobic power output adaptations in male TT players. We hypothesized that CS would lead to greater adaptive changes compared to TS in physical performance adaptations of TT players.

Materials and methods

Participants

The appropriate sample size for this research was determined using G*Power software (Version 3.1.9.2, University of Kiel, Germany). The calculations incorporated an effect size of 0.8, a power of 0.8, and a significance level of 0.05, drawing on findings from a prior study by Dehua¹³ that examined the effects of upper limb strength training on physical fitness adaptations of TT players. Consequently, it was established that a total of 8 subjects would be adequate for each group. Therefore, forty young male TT players were recruited from a local academy and after determining their dominant hand were randomly divided into CS-PT, TS-PT, CS-RT, TS-RT, and active control (CON) groups (Table 1). All subjects were familiar with RT and PT techniques for both upper and lower body but had not engaged in RT and PT training for at least 6 months prior to the study. Before data collection, all subjects provided written informed consent after being informed about the study's purpose, procedures, potential risks, and benefits. They were required to carefully read and sign the informed consent form, which had been approved by the Ethics Research Committee of the Shandong Sport University and was in accordance with the Declaration of Helsinki. Furthermore, a specialist sports medicine physician screened the subjects to ensure they had no orthopedic issues or upper body injuries that would prevent them from participating in the study.

Experimental design

The research was conducted to examine the effects of four different training methods (CS-PT, TS-PT, CS-RT, and TS-RT) on various aspects of upper body performance in male TT players over a longitudinal study period (Fig. 1). All participants engaged in TT practice three days a week, with the training groups undergoing RT or PT with different rest distributions (CS or TS) on Tuesday, Thursday, and Saturday. Prior to the start of the training period, the subjects were familiarized with the testing and training procedures, and their anthropometric profiles were assessed. Two days after the familiarization session, the players were brought to the laboratory for measurements of upper body muscular power (medicine ball throw) and maximal strength (bench press) (i.e., Wednesday). On Friday, the subjects returned to the laboratory for measurements of reaction time and arm crank anaerobic power test. These assessments were repeated after the 8-week training period in the same sequence. All testing sessions were conducted between 3:00 and 6:00 PM, and participants were instructed to avoid any additional

	CS-PT (n = 8)	TS-PT (n = 8)	CS-RT (n = 8)	TS-RT (n = 8)	CON (n = 8)	p-value
Age (y)	19.4 ± 1.2	19.7 ± 1.4	19.5 ± 1.8	19.6 ± 1.1	19.2 ± 1.1	0.962
Height (cm)	179.4 ± 4.1	180.8 ± 5.5	179.4 ± 4.6	178.8 ± 4.5	176.8 ± 3.7	0.748
Body mass (kg)	77.8 ± 5.3	79.2 ± 5.8	78.8 ± 4.2	76.2 ± 4.8	78.2 ± 5.8	0.536
TT experience (y)	4.2 ± 0.6	4.6 ± 0.9	4.4 ± 0.5	4.9 ± 0.4	4.9 ± 0.4	0.864

Table 1. Subject characteristics (mean ± SD). CS-PT cluster sets plyometric training, TS-PT traditional sets plyometric training, CS-RT cluster sets resistance training, TS-RT traditional sets resistance training, TT table tennis.

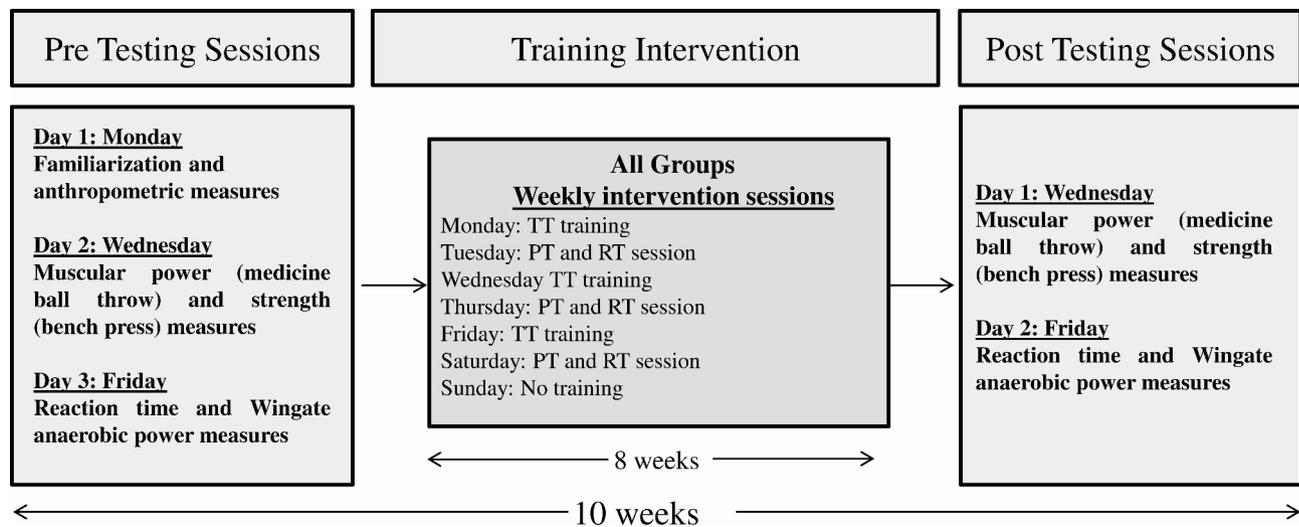


Fig. 1. Study design.

exercise or training during the study period while maintaining their regular daily activities. Furthermore, the participants were advised to refrain from consuming caffeine or alcohol prior to and during the testing sessions.

Anthropometric measures

The measurement of height was conducted utilizing a wall-mounted stadiometer (Seca 222, Terre Haute, IN) and recorded with an accuracy of 0.1 cm. For body mass measurement, a medical scale (Tanita, BC-418MA, Tokyo, Japan) was used with an accuracy of 0.1 kg²⁷.

Medicine ball throw test

To evaluate the upper body muscular power in TT players, the seated medicine ball (i.e., 3 kg) chest throw was utilized³⁰. After a 15-minute general warm-up, each subject underwent three trials to become familiar with the test and engage in a specific warm-up routine. Following the warm-up, subjects sat on the ground with their backs against the wall, legs fully extended and spread wide. Upon the command “GO,” subjects were required to throw the ball from their chest when the elbow reached flexion (approximately 90°), exerting maximal effort and extending their arms. These trials were repeated three times with a 1-min rest period in between, and the best score in cm was recorded for further analysis. The reliability coefficient (ICC) of this assessment was found to be 0.95.

Upper body maximal strength

In order to evaluate the maximum strength of the upper body, the bench press 1RM test was carried out using free weights (Nebula Fitness, Ohio, USA)²⁹. After a general warm-up, the subjects engaged in a specific warm-up routine that involved performing eight to ten repetitions with a light weight. Following this, the subjects underwent the strength test, gradually increasing the resistance until they reached the point of volitional failure while maintaining proper technique and a full range of motion. The 1RM was determined by successfully achieving the maximum lift within five attempts, with a 3–5-min rest period between each set. Throughout the testing session, specialist strength and coach offered verbal encouragement and ensured the safety of each subject. The ICC of this test was measured at 0.94.

Reaction time test

The measurement of reaction time was conducted using the electronic timing system ($\pm 1/1,000$, Newtest, Oulu, Finland), by incorporating a digital display, a light, and a button²⁹. The subjects were seated in a calm environment, with their resting arm placed on the table and their second index finger positioned one cm away from the button. They were given instructions to press the button whenever a visual stimulus appeared, which was randomly assigned to their dominant hand. The mean score of the last five trials out of ten repetitions was recorded for further analysis. The ICC of this test was obtained at 0.96.

Wingate anaerobic power test

In order to evaluate the upper body anaerobic power performance of TT players, the 30-s Wingate anaerobic power test was administered. Following a 5-min warm-up, the participants were required to exert their maximum effort on a mechanically braked arm ergometer (891E; Monark, Vansbro, Sweden), with the resistance calibrated to 0.050 kg per kilogram of body weight. They were instructed to initiate the cranking motion quickly, pushing against the inertial resistance³¹. Throughout the test, consistent verbal encouragement was provided and the highest power achieved at the 5-s mark was determined for peak power output, while mean power output was recorded by the average power output throughout the entire 30-s test^{32,33}.

Training program

All subjects (CS-PT, TS-PT, CS-RT, TS-RT and CON) engaged in their tennis training sessions on Monday, Wednesday, and Friday afternoons, lasting between 80 and 90 min including forehand to forehand counterhit, forehand loop to block, backhand loop to block, push to push, serve exercises and competitive games. The training groups (CS-PT, TS-PT, CS-RT, and TS-RT) participated in three training sessions per week on Tuesday, Thursday, and Saturday. Both the RT and PT programs comprised nonlinear, multi-set, multi-exercise programs in which the intensity and volume changed weekly (Table 2)^{20–22}. The volume load and rest interval among the groups were the same throughout the training period. All training sessions were monitored with the trained researcher and in each training session a specialist strength and conditioning coach supervised players (with a ratio of 1:4, trainer: player) to ensure proper execution, appropriate loads and rest intervals.

Statistical analysis

The data was presented using the mean \pm SD. To analyze the normality of the dependent variables, the Shapiro-Wilk Normality test was conducted. The percent change ($\Delta\%$) was calculated for each variable using the formula $[\text{post-intervention} - \text{pre-intervention}] / \text{pre-intervention} \times 100$. A 5 (group) \times 2 (time) ANOVA was performed to determine significant differences between the groups in variable measures. If a significant F value was obtained, the Bonferroni post hoc test was applied. Effect sizes (ES) for variables were calculated using Hedges' g and categorized as trivial (<0.20), small ($0.20-0.60$), medium ($0.60-1.20$), large ($1.20-2.00$), or very large (>2.00). The 95% confidence interval (CI) was also reported³⁷. The significance level was set at 0.05.

Results

All subjects involved in this study demonstrated complete compliance, accomplishing a perfect success rate of 100%. Additionally, there were no reported incidents of injuries associated with the training and testing interventions employed. Prior to the intervention, there were no significant differences observed among the groups, but subsequent to the intervention, significant differences ($p < 0.05$) between the CON and training groups were noted. Furthermore, the CON group, which exclusively underwent the TT training, did not display any significant changes in their measured variables from pre- to post-intervention.

All training groups indicated significant gains in muscular power measured by medicine ball throw following the 8-week training (Table 3). There was a significant group \times time interaction in the muscular power ($p = 0.001$), indicating greater training effects for the PT groups than the RT groups (CS-PT vs. CS-RT, standard mean difference [SMD] = 0.39, 95% CI -0.62 to 1.36 , $p = 0.021$; TS-PT vs. TS-RT, SMD = 0.47, 95% CI -0.53 to 1.46 , $p = 0.018$) following the 8-week intervention (Fig. 2). However, no significant differences were observed between the CS and TS configurations in both the RT and PT programs.

Significant maximal strength gains were observed by groups following the 8-week training intervention (Table 3). There was a significant group \times time interaction in the maximal strength performance ($p = 0.001$), indicating greater training effects for the RT groups than the PT groups (CS-RT vs. CS-PT, SMD = 0.39, 95% CI -0.60 to 1.38 , $p = 0.033$; TS-RT vs. TS-PT, SMD = 0.23, 95% CI -0.75 to 1.21 , $p = 0.048$) following the 8-week intervention (Fig. 3). Nonetheless, there were no significant differences noted between the CS and TS configurations in both the RT and PT regimens.

The reaction time decreased significantly for all training groups (i.e., Moderate ES) following the 8-week resistance and plyometric training intervention (Table 3), without any significant differences among the groups (Fig. 4).

The results showed that all training groups significantly improved anaerobic power output ranging between small to large ES which was measured by the Wingate test after completing the 8-week training period (Table 3). A significant group \times time interaction was noted in peak and mean power output ($p = 0.001$), indicating that the PT groups experienced greater training effects compared to the RT groups (peak power: CS-PT vs. CS-RT, SMD = 0.87, 95% CI -0.20 to 1.85 , $p = 0.017$; TS-PT vs. TS-RT, SMD = 0.88, 95% CI -0.19 to 1.86 , $p = 0.011$; mean power: CS-PT vs. CS-RT, SMD = 0.75, 95% CI -0.30 to 1.72 , $p = 0.024$; TS-PT vs. TS-RT, SMD = 0.66, 95% CI -0.35 to 1.66 , $p = 0.042$) following the 8-week intervention (Fig. 5). However, there were no significant differences observed between the CS and TS configurations in both the RT and PT programs.

Wk	Workshop	Sets	Repetitions	Set type	Rest (s)	Intensity
1–2	PT: MB* chest pass, MB slams, seated throw circuit, lying MB drop	3	10	CS: 2 \times 5, TS: 1 \times 10	CS: 30/60, TS: 90	ME
	RT: barbell bench press, shoulder press, dumbbell front rise, cable pulldowns	3	10	CS: 2 \times 5, TS: 1 \times 10	CS: 30/60, TS: 90	RM
3–4	PT: MB chest pass, MB slams, seated throw circuit, lying MB drop	3	12	CS: 2 \times 6, TS: 1 \times 12	CS: 30/60, TS: 90	ME
	RT: barbell bench press, shoulder press, dumbbell front rise, cable pulldowns	3	12	CS: 2 \times 6, TS: 1 \times 12	CS: 30/60, TS: 90	RM
5–6	PT: MB chest pass, MB slams, seated throw circuit, lying MB drop	4	10	CS: 2 \times 5, TS: 1 \times 10	CS: 30/60, TS: 90	ME
	RT: barbell bench press, shoulder press, dumbbell front rise, cable pulldowns	4	10	CS: 2 \times 5, TS: 1 \times 10	CS: 30/60, TS: 90	RM
7–8	PT: MB chest pass, MB slams, seated throw circuit, lying MB drop	4	12	CS: 2 \times 6, TS: 1 \times 12	CS: 30/60, TS: 90	ME
	RT: barbell bench press, shoulder press, dumbbell front rise, cable pulldowns	4	12	CS: 2 \times 6, TS: 1 \times 12	CS: 30/60, TS: 90	RM

Table 2. Training program. MB = medicine ball, *5% of body weight⁴⁰, ME = maximal effort, RM = repetition maximum. 120-sec rest between exercises were allowed for recovery. CS cluster sets, TS traditional sets, PT plyometric training, RT resistance training.

Variables	Groups	Pre-intervention	Post-intervention	ES with 95% CI	Interaction effect
Medicine ball throw (cm)	CS-PT	609.3 ± 43.1	669.8 ± 49.2*†	1.24 (0.17 to 2.31) Large	$F_{2,7} = 25.0, p = 0.001$
	TS-PT	611.6 ± 42.6	657.1 ± 42.0*†	1.02 (-0.02 to 2.06) Medium	
	CS-RT	611.3 ± 50.9	651.6 ± 43.1*	0.81 (-0.21 to 1.83) Medium	
	TS-RT	607.1 ± 43.7	636.2 ± 42.8*	0.64 (-0.37 to 1.64) Medium	
	CON	610.2 ± 42.3	613.1 ± 42.4	0.06 (-0.92 to 1.04) Trivial	
Maximal strength (kg)	CS-PT	63.7 ± 11.2	68.3 ± 10.8*	0.40 (-0.59 to 1.38) Small	$F_{2,5} = 11.8, p = 0.001$
	TS-PT	63.1 ± 9.9	67.6 ± 9.7*	0.43 (-0.56 to 1.43) Small	
	CS-RT	65.6 ± 10.5	73.2 ± 12.7*‡	0.62 (-0.39 to 1.62) Medium	
	TS-RT	63.1 ± 9.8	70.2 ± 11.6*‡	0.63 (-0.38 to 1.63) Medium	
	CON	64.3 ± 9.0	66.0 ± 9.1	0.18 (-0.80 to 1.16) Trivial	
Reaction time (ms)	CS-PT	250.7 ± 14.3	239.7 ± 15.1*	-0.71 (-1.72 to 0.3) Medium	$F_{2,3} = 13.9, p = 0.027$
	TS-PT	248.1 ± 13.6	237.2 ± 16.7*	-0.68 (-1.68 to 0.33) Medium	
	CS-RT	252.3 ± 9.2	242.6 ± 12.6*	-0.83 (-1.85 to 0.19) Medium	
	TS-RT	248.0 ± 13.4	238.3 ± 16.6*	-0.61 (-1.61 to 0.39) Medium	
	CON	253.6 ± 14.7	249.3 ± 14.8	-0.28 (-1.26 to 0.71) Small	
Peak power output (w)	CS-PT	483.7 ± 31.8	543.2 ± 29.8*†	1.83 (0.66 to 2.99) Large	$F_{2,1} = 68.8, p = 0.001$
	TS-PT	486.8 ± 32.4	546.6 ± 35.6*†	1.66 (0.52 to 2.80) Large	
	CS-RT	485.2 ± 32.2	516.0 ± 32.5*	0.90 (-0.13 to 1.93) Medium	
	TS-RT	484.8 ± 37.9	512.8 ± 40.8*	0.67 (-0.34 to 1.68) Medium	
	CON	483.5 ± 38.8	488.5 ± 37.2	0.12 (-0.86 to 1.11) Trivial	
Mean power output (w)	CS-PT	338.8 ± 29.2	365.6 ± 27.8*†	0.89 (-0.14 to 1.92) Medium	$F_{2,8} = 39.4, p = 0.001$
	TS-PT	337.5 ± 27.4	362.6 ± 25.7*†	0.89 (-0.13 to 1.92) Medium	
	CS-RT	329.2 ± 25.9	345.0 ± 27.1*	0.57 (0.43 to 1.57) Small	
	TS-RT	330.5 ± 23.0	345.3 ± 24.1*	0.59 (-0.41 to 1.60) Small	
	CON	329.2 ± 17.8	331.6 ± 17.2	0.13 (-0.85 to 1.11) Trivial	

Table 3. Physical performance changes from pre to post-intervention (mean ± SD). *significant differences compared with Pre and CON ($p < 0.05$). †significant differences compared with RT ($p < 0.05$). ‡significant differences compared with PT ($p < 0.05$). CS-PT cluster sets plyometric training, TS-PT traditional sets plyometric training, CS-RT cluster sets resistance training, TS-RT traditional sets resistance training.

Discussion

The objective of this study was to examine the impact of CS and TS configurations in PT and RT programs on the upper body physical performance attributes of young male TT players. The findings revealed that PT yielded superior results in terms of muscular and anaerobic power performance, whereas RT was more effective in promoting muscular strength gains. Interestingly, all interventions demonstrated similar improvements in reaction time, with no significant variations among the groups. Furthermore, within each PT or RT group, no significant differences were observed between CS and TS configurations.

The study revealed a significant increase in muscular power and anaerobic power performance after 8 weeks of training with both PT and RT using CS and TS configurations. Comparing the PT and RT groups, it was found that the PT groups showed greater power performance than the RT groups for both set configurations. Specifically, the CS-PT and TS-PT groups exhibited more adaptive changes in power performance compared to the CS-RT and TS-RT groups. These results support previous research^{15,16,28,38} indicating that PT is more effective than RT in promoting power gains through adaptations. The improvement in muscular power performance, as measured by medicine ball throw, may be attributed to factors such as increased rate of force development, firing rate, neuromuscular adaptations, and muscle fiber recruitments induced by PT, which were higher compared to RT^{15,20–22}. The result suggests that conducting upper body PT with maximum effort led to a more significant release of calcium and recruitment of type II muscle fibers³⁹, resulting in a greater stretch-shortening cycle (SSC) adaptations (i.e., a rapid stretch followed by a rapid contraction) allowing for greater muscle fiber adaptation than RT which allows for more adaptive changes in power performance²⁸.

PT resulted in a greater increase in anaerobic power output, specifically in mean and peak power output as measured by the Wingate test, compared to RT. This suggests that performing high-intensity upper body PT trials with maximal effort leads to metabolic adaptations in anaerobic pathways such as ATP-PCr and glycolytic¹. The large training effects observed in peak power output and the moderate ES in mean power output indicate that PT, which involves very short trial durations, primarily activates ATP-PCr pathways^{35,36}. On the other hand, a series of upper body PT trials may predominantly engage anaerobic glycolytic pathways⁴⁰, resulting in greater adaptations in power output compared to RT. However, it is important to note that neither PT nor RT set configurations had a more significant impact on power performance adaptations, aligning with a recent review study that found no superiority of CS over TS configurations in terms of power performance gains²³.

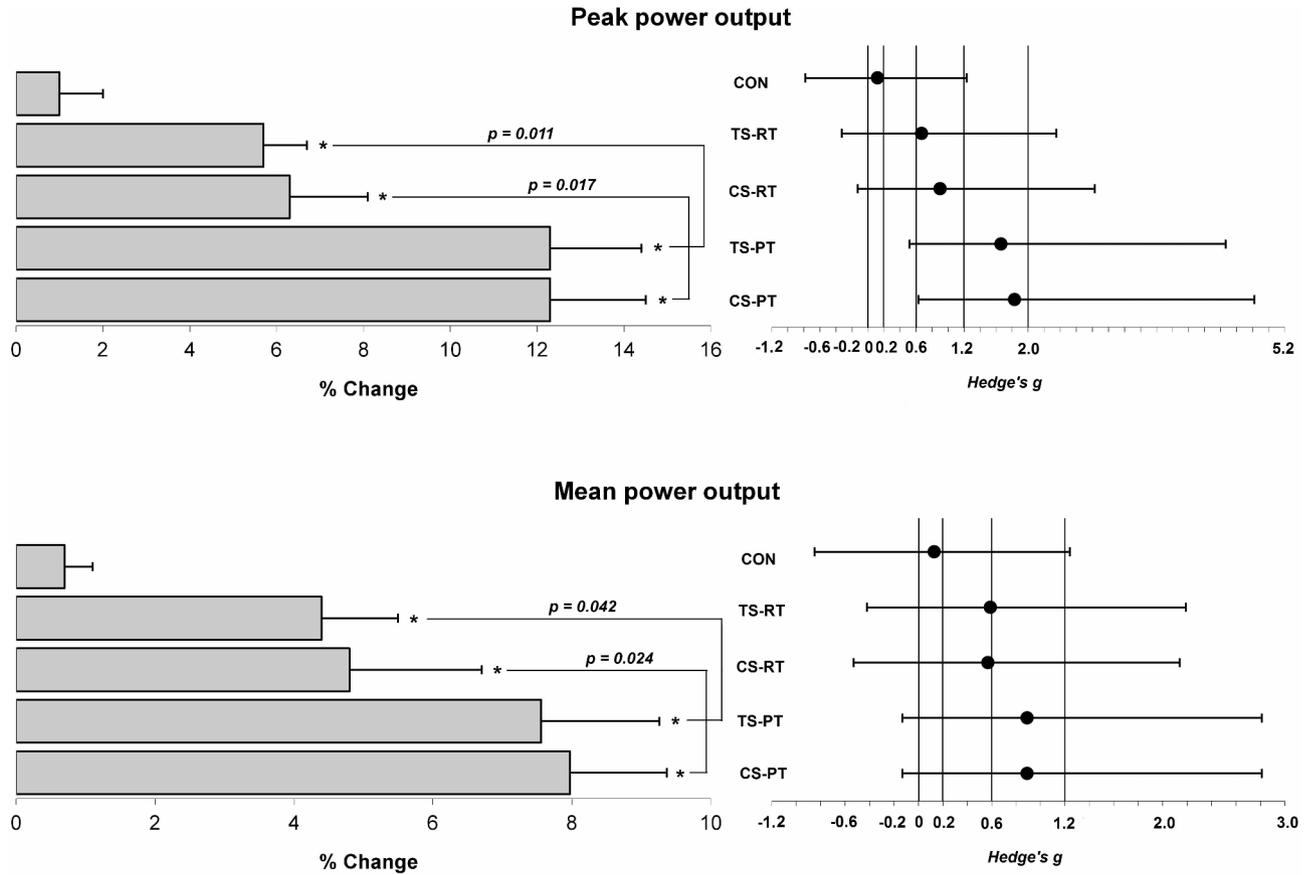


Fig. 2. Percent change and ES (with 95% CI) in muscular power after training intervention for the groups.*Significant differences compared with CON ($p < 0.05$).

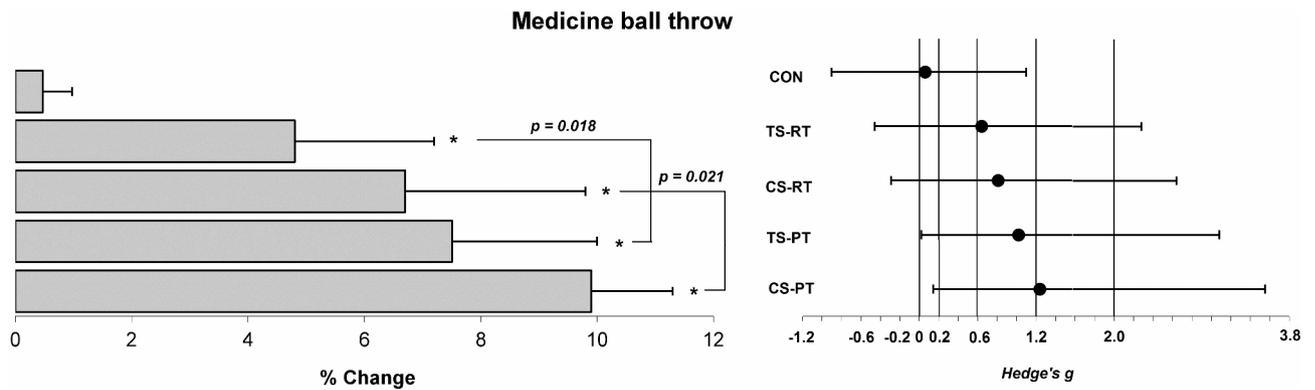


Fig.3. Percent change and ES (with 95% CI) in muscular strength after training intervention for the groups.*Significant differences compared with CON ($p < 0.05$).

The strength performance significantly increased following the RT and PT interventions, while no further effects were seen with the inclusion of CS instead of TS. Both CS and TS RT groups demonstrated greater strength gains compared to the PT groups, highlighting the superiority of RT over PT in promoting strength improvements. However, the impact of set configurations on strength performance was considered to be insignificant. Previous studies have also reported an increase in upper body strength performance after RT and PT^{21,40}, which is consistent with the results observed in TT players following ballistic and PT programs^{6,11-13}. The earlier mechanism related to increase in maximal strength after a training period may be attributed to neuromuscular adaptations (such as improved excitability of motor neurons, an increase in the recruitment of motor units, or enhanced activation of synergistic muscles, or potentially all of these factors)¹⁵. Furthermore,

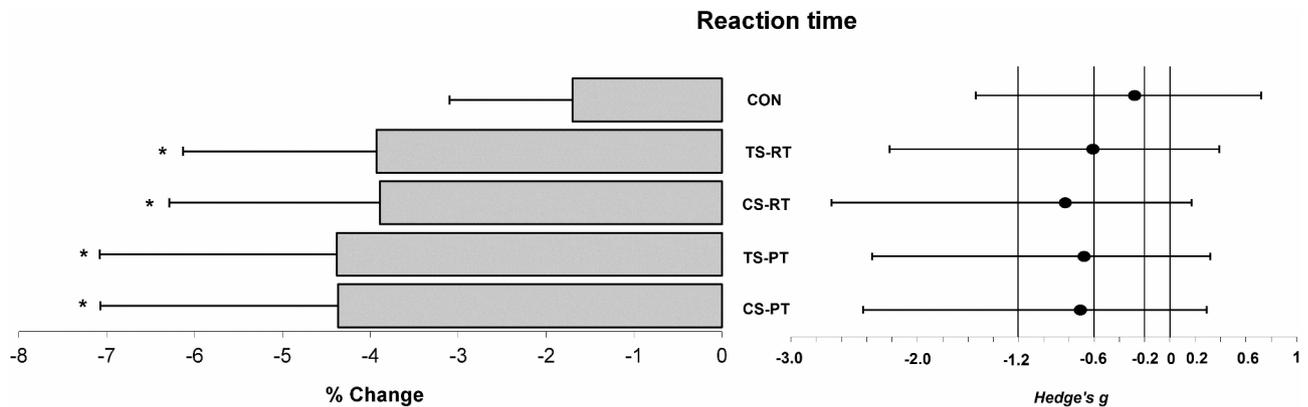


Fig. 4. Percent change and ES (with 95% CI) in reaction time after training intervention for the groups. *Significant differences compared with CON ($p < 0.05$).

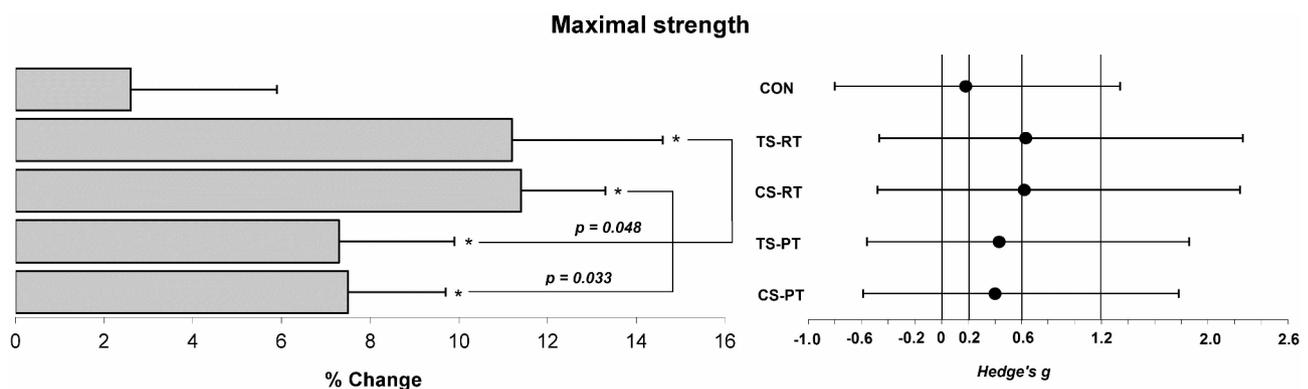


Fig. 5. Percent change and ES (with 95% CI) in anaerobic power output after training intervention for the groups. *Significant differences compared with CON ($p < 0.05$).

training may lead to muscular hypertrophy⁴¹, which could be another mechanism related to strength gains following the duration of training period⁴². The specificity principle of training could explain why RT elicits more adaptive responses in strength performance compared to PT⁴². It seems that the RT groups engaged similar muscle groups, such as the bench press and shoulder press, resulting in a positive transfer effect on the one repetition maximum of the bench press exercise.

In regards to the integration of CS and TS configurations, while certain studies have highlighted the advantages of TS²⁶, others have found greater benefits with CS⁴³. A recent study conducted by Davies et al.²³ concluded that CS and TS configurations result in similar neuromuscular and muscular adaptations. Furthermore, incorporating these training set configurations proves similarly effective in eliciting adaptive responses and yielding comparable training benefits for TT players.

Reaction time is an essential skill in the sport of TT, as it measures the duration between a sensory stimulus and the subsequent reaction⁴⁴. This skill is crucial in order to accurately predict the direction and speed of the ball⁴⁵. The results of the present study indicated that both the RT and PT induced adaptations in reaction time and no further effects were observed by PT or RT and or incorporating CS or TS configurations. The reductions in reaction time observed in both RT and PT may be attributed to enhancements in the sensory transmission of input, the duration of motor execution, and the efficiency of control processing, resulting in adaptations within the sensory-motor system²⁹.

The organization of the motor control system is intricately tied to its capability to respond to visual stimuli in sports⁴⁶. This capability is influenced by the information provided by the perceptual system, which impacts the reaction time in TT players. It appears that both PT and RT contribute to these adaptations, resulting in reduced reaction time similar to previous studies that reported the positive effects of different forms of training on upper body reaction time²⁹.

Limitation and perspectives

The present investigation identifies several methodological limitations that require further examination. Firstly, the limited sample size of athletes ($n = 8$ for each group) has influenced the statistical power of the findings. Nevertheless, a priori power analysis has been performed, suggesting that this sample size is sufficient

for achieving an adequate level of statistical power. Secondly, the outcomes of this research are confined to male TT players and focus solely on the upper body. Further studies are essential to determine whether these results can be extrapolated to the lower body of TT players or to athletes in other sports, such as basketball or handball, across various age groups and fitness levels. Lastly, it would have been advantageous to incorporate additional physiological measures, including electromyography (EMG) to assess neuromuscular adaptations, as well as evaluations of muscular hypertrophy (e.g., B-mode ultrasound) to explore the mechanisms underlying adaptations in power and strength following CS and TS plyometric and resistance training. To substantiate our findings, future research should consider these variables. Given these limitations, we recommend that subsequent studies investigate different athletic populations or examine physiological factors that may influence the effectiveness of CS and TS plyometric and resistance training regimens. However, this study also possesses several strengths and perspectives that could contribute to the understanding of conditioning in TT players. It is noteworthy that both training approaches aimed at enhancing upper body power and strength were analyzed within a single study while controlling for variables that could impact the results. Additionally, this research evaluated both common set configurations (i.e., CS and TS) during plyometric and resistance training, which could serve as an effective study design to elucidate the superiority of each training method and set configuration in TT players, particularly concerning the upper body, an area that has received less attention in prior studies.

Practical application

The results of our research indicate that the integration of both PT and RT with varying set configurations over an 8-week period, in conjunction with TT training, can lead to significant enhancements in the physical performance of TT athletes. Coaches and trainers working with TT players may find it beneficial to incorporate both PT and RT to enhance physical capabilities. PT is particularly advantageous when players require improvements in muscular and anaerobic power, especially during specific phases of the annual training plan. Conversely, RT is more effective for enhancing strength performance and is recommended during the general training phase. However, no additional benefits were noted for any specific set configuration compared to others.

Conclusion

The inclusion of an 8-week upper body PT and RT program resulted in improved physical performance for TT players. Moreover, there were no significant differences in the adaptations of physical performance attributes between the CS and the TS. PT seems to be more effective in stimulating positive changes in muscular power and anaerobic power output. Conversely, RT is more advantageous in enhancing maximal strength for TT players. Therefore, PT is recommended for enhancing power performance, while RT is preferred for increasing strength, and no additional effects were observed by incorporating different set configurations.

Data availability

The datasets used and analyzed during the current study are available from the corresponding author (X.Z) upon reasonable request.

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Author contributions

X.Z. P.S. and F.L. contributed equally to every aspect of this experiment, including conceptualization, study design, supervision, data collection, statistical analysis, interpretation, writing, and reviewing. All authors reviewed and endorsed the final version of the manuscript.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

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