

The impact of different combinations of plyometric training on the physical performances: experimental study on student-athletes

El impacto de diferentes combinaciones de entrenamiento pliométrico en el rendimiento físico: estudio experimental en estudiantes-atletas

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Abstract. Plyometric training (PT) can be performed in a variety type of exercises involving the stretch-shortening cycle (SSC) in lower limbs. Numerous research has examined the impact of plyometric exercise on various sport performances in various populations over the past few decades. The objective of this research is to analyse the effect of combined plyometric exercises on strength, speed, and power in student-athletes. Thirty-three student athletes were classified into three experimental groups and were given six weeks of respected training specific to their group: CS (continue board jump + skater hops), TI (tuck jump + ins and outs), and ST (standard conventional training). Pretest and posttest measures on strength, power, and speed were obtained. Data analysis was done using Wilcoxon signed rank and Kruskal-Wallis test to examine group differences. Follow up test was done using Mann-Whitney whenever a statistically significant different was identified between groups. It was found that strength increased significantly after PT was done for six weeks ($p=0.000$), with CS showed highest improvement. Between-group difference was only found in strength which were between CS-TI ($p=0.000$) and ST-TI ($p=0.020$) pairs. Based on these findings, it was concluded that combined plyometric trainings done in six weeks were able to improve strength, power, and speed in student-athletes.

Keywords: Physical performance; plyometric training; power; speed; strength; stretch-shortening cycle

Resumen. El entrenamiento pliométrico (PT) se puede realizar en una variedad de tipos de ejercicios que involucran el ciclo de estiramiento-acortamiento (SSC) en las extremidades inferiores. Numerosas investigaciones han examinado el impacto del ejercicio pliométrico en diversos rendimientos deportivos en diversas poblaciones durante las últimas décadas. El objetivo de esta investigación es analizar el efecto de los ejercicios pliométricos combinados sobre la fuerza, velocidad y potencia en estudiantes-atletas. Treinta y tres estudiantes atletas fueron clasificados en tres grupos experimentales y recibieron seis semanas de entrenamiento respetado y específico para su grupo: CS (salto continuo sobre tabla + saltos de patinador), TI (salto hacia abajo + entradas y salidas) y ST (entrenamiento convencional estándar). Se obtuvieron medidas pretest y posttest de fuerza, potencia y velocidad. El análisis de los datos se realizó mediante el rango con signo de Wilcoxon y la prueba de Kruskal-Wallis para examinar las diferencias entre los grupos. La prueba de seguimiento se llevó a cabo utilizando Mann-Whitney siempre que se identificó una diferencia estadísticamente significativa entre los grupos. Se encontró que la fuerza aumentó significativamente después de realizar el PT durante seis semanas ($p=0,000$), y el CS mostró la mayor mejora. La diferencia entre grupos solo se encontró en la fuerza, que fue entre los pares CS-TI ($p=0,000$) y ST-TI ($p=0,020$). Con base en estos hallazgos, se concluyó que el entrenamiento pliométrico combinado realizado en seis semanas pudo mejorar la fuerza, la potencia y la velocidad en los estudiantes-atletas.

Palabras clave: Desempeño físico; entrenamiento pliométrico; fuerza; velocidad; fortaleza; ciclo de estiramiento-acortamiento

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Introduction

Several physical capacities such as power, strength, and speed are considered important factors of athletic performance (Kobal et al., 2017), especially in intermittent sport which is popular among young people such as soccer (Diaz-Ochoa, Gomez-Renand, Hoyos-Flores, & Hernandez-Cruz, 2023), futsal, or basketball (Naser et al., 2017). Either those sports are played as competitive game or simply as recreational activity, good physical performances are required for the game (Dobreff et al., 2020). According to certain theory, the high degree of plasticity in neuromuscular development during pre-adolescence period (Chmielewski, Myer, Kauffman, & Tillman, 2006), coupled with appropriately planned implementation of integrative neuromuscular exercise such as additional training program consisting of a combination between general and specific strength and conditioning exercise (Pereira et al., 2024), may allow to enhance physical

development that favourably influences to athleticism during adulthood (Myer et al., 2011; Ramírez-Campillo et al., 2015). For this reason, coaches, practitioners, and researchers keep searching the most effective training method to improve these specific muscular and neuromuscular abilities especially in young players or adolescents specific to their sports (Cormie et al., 2011). With this regard, plyometric training becomes the most frequently used exercise to boost physical performances (Kobal et al., 2017; Lamas et al., 2012).

Plyometric training (PT) is popular training method used in all type of sport activities especially among people playing dynamic and fast-paced sports (Benzidane et al., 2015; Váczi et al., 2013). Plyometric training is a common form of physical conditioning in which body movements are performed with the principle of stretch-shortening cycle (SSC) (Bulqini et al., 2023; Putera et al., 2023). SSC works by utilizing the elastic attributes of muscle fibres and connective tissues, facilitating them to store elastic energy

during the deceleration phase and release it immediately during the acceleration phase to generate maximal force and mechanical work of the muscle in the shortest time (Radnor et al., 2018; Sole et al., 2021).

Plyometric training has been extensively used to enhance human neuromuscular function and to improve performance in both explosive and endurance sport activities involving jumping and sprinting (Agostini et al., 2017; Kons et al., 2023; Ramirez-Campillo et al., 2018). Several studies observed that some physical capacities that could be improved using plyometric training are muscle power, muscle strength, explosive strength, sprint time, and change of direction (CoD) ability (Ache-Dias et al., 2016; Kons et al., 2023). Meanwhile, previous researches considered PT as a suitable type of exercise for enhancing balance, agility, and speed in athletes (Michailidis et al., 2013; Ramachandran et al., 2021; Ramirez-Campillo et al., 2018). Plyometric training is also associated with changes in the neuronal and muscle mechanical characteristics (e.g., musculotendinous stiffness and architecture), which may account for the improvement in the aforementioned physical capacities (Andrade et al., 2018).

Different type of plyometric exercises has been used since the last seven decades to improve physical fitness and performance of adolescent students (Hariyanto et al., 2022; Kons et al., 2023). The training program is also incorporated with combinations between traditional plyometric training (standing jump, drop jump, multiple hops and jumps, bounds), assisted (exercise is assisted with something e.g. elastic band), and resisted (exercise performed under varied condition, type of surface, and additional external loads) (Makaruk et al., 2020). However, until this date, only little is known about which type of plyometric gives the best impact on sport performances. In addition to that, there is still no agreement about the most appropriate combination of plyometric training for adolescents. As specificity is an essential prerequisite for training-induced adaptation, specific training strategies may be necessary for performance improvement in explosive neuromuscular actions (Ramírez-Campillo et al., 2015). Given the aforementioned limitations, we conduct this research to measure the effect of combined plyometric exercises on strength, speed, and power in adolescent students.

Material and Methods

Study Design and Participants

This research was an experimental study using pretest and posttest control group design. The participants were thirty-three (15.01 ± 0.55 year; 45.90 ± 8.85 kg, 154.20 ± 6.41 cm) students with no background in plyometric training were selected based on the following criteria: (1) age 12-15 years; (2) male students; (3) free from injury, disease, or any chronic conditions during the last six months that may limit their ability to perform the exercise protocol; (4) registered as an active member of school's sport club;

and (5) agree to complete all the training sessions. Prior to the study, all participants (with their parents or legal guardians) were informed the nature of the training protocols along with benefits and possible risks associated with participation in this study. Only those who voluntarily gave the consent to participate in this study were included.

Afterward, all thirty-three participants were classified into three groups consisted of 11 students each: CS (continue board jump + skater hops), TI (tuck jump + ins and outs), and ST (standard conventional training). They were then instructed to avoid heavy activity or high-intensity exercise at least a day (24 hours) before the pretest (first day) and posttest (last day). All the protocols were done in accordance to the research policy procedures of Universitas Negeri Surabaya and was approved by ethical committee of Airlangga University.

Treatment Procedure

The training protocol consists of conventional training and combination of plyometric training (continue board jump, skater hops, ins and outs) which were performed three times a week for six weeks. The training was scheduled on non-consecutive days to provide time for recovery and regeneration, made up to 18 sessions. Each session was begun with a 10-minute of warming up and followed by the actual training session according to their respected groups, done in three sets with two minutes of rest between each set. The intensity of the training was started at 80%, then it was increased gradually up to 100% every two weeks. All sessions were observed thoroughly and evaluation was written weekly in journal logbook for each subject.

Instrument and Data collection

A baseline data was obtained in the beginning of the experimental period to measure anthropometric variables such as age (year), bodyweight (kg), height (cm), body mass index (BMI; kg/m^2), heart rate (HR; bpm), and blood pressure (SBP and DBP; mmHg). A digital weighing scale (Omron HN-289, Osaka, Japan) was used to assess bodyweight. Subjects' height was measured using portable stadiometer (Seca 213, California, US) at the nearest 0.1 cm. Heart rate was observed and tracked using a polar heart rate monitor (Polar H10 Bluetooth Heart Rate Sensor & Fitness Tracker, Kempele, Finland), and a digital blood pressure meter (Omron Deluxe HEM-8712, Osaka, Japan) was used to check the subjects' diastolic and systolic blood pressure. All equipment and devices were properly calibrated before used.

Data regarding physical performances were obtained before the first session of training protocols as pretest. A calibrated Back & Leg Dynamometer (Takei 5002, Takei, Japan) was used to measure leg's strength. Leg power was measured using a digital Jump DF (Takei 5414 Jump-DF Digital Vertical, Takei, Japan). Strength and power tests were done three times with two-minutes break between each attempt, and the greatest score was recorded as the

final data. Lastly, 30-m sprint time was recorded using an electronic timing system to measure speed (Microgate SARM, Bolzano, Italy). All measurements were repeated in the last training session as posttest data.

Statistical analysis

All data were analysed in descriptive statistic and reported as means and standard deviations (SD). Quantitative data were verified in terms of normal distribution using Shapiro-Wilk, followed by non-parametric Wilcoxon signed rank test to analyse the differences in physical performance variables before (pretest) and after (posttest) the training was done for six weeks. Kruskal-Wallis test was used to examine group differences between CS, TI, and ST. Follow up test was done using Mann-Whitney whenever a statistically significant difference was identified between groups. Differences were considered significant if p -value ≤ 0.05 . Computations were performed using SPSS 23 for Mac

(SPSS Inc., Chicago, USA) and GraphPad Prims 9.0 for Mac (GraphPad Software Inc., San Diego, USA).

Results

The demographic data of participants are shown in Table 1. The highest average of participants' age and systolic blood pressure were found in TI group, which were 15.38 ± 0.73 years and 129.08 ± 5.64 mmHg, respectively. Meanwhile, the highest average bodyweight (45.55 ± 4.32 kg), height (157.18 ± 8.12 cm), heart rate (77.90 ± 17.46 bpm), and diastolic blood pressure (66.88 ± 5.97 mmHg) were observed in CS group. Lastly, the highest average of body mass index was found in ST group (18.95 ± 10.57 kg·m⁻¹). Significant differences were observed in age, bodyweight, and body mass index, with p -value 0.032, 0.000, and 0.006, respectively.

Table 1.
Descriptive statistic of participants (N=33)

Variable	CS	TI	ST	Sig.
Age (year)	14.91 \pm 0.67	15.38 \pm 0.73	14.24 \pm 0.59	0.032**
Bodyweight (kg)	45.55 \pm 4.32	43.82 \pm 8.17	41.91 \pm 8.90	0.000**
Height (cm)	157.18 \pm 8.12	153.91 \pm 8.37	154.55 \pm 8.91	0.088
Body mass index (kg/m ²)	18.35 \pm 9.20	18.49 \pm 10.65	18.95 \pm 10.57†	0.006**
Heart rate (bpm)	77.90 \pm 17.46	76.31 \pm 9.95	76.19 \pm 0.65	0.095
Diastolic blood pressure (mmHg)	66.88 \pm 5.97	64.55 \pm 5.87	66.47 \pm 8.92†	0.110
Systolic blood pressure (mmHg)	127.70 \pm 16.37	129.08 \pm 5.64	121.92 \pm 10.08	0.244

All data were presented in mean and standard deviation (mean \pm SD)

CS: Continue board jump + skater hops; TI: Tuck jump + ins and outs; ST: Standard conventional training

* Significantly different with CS group ($p \leq 0.05$) (Kruskal-Wallis)

† Significantly different with TI group ($p \leq 0.05$) (Kruskal-Wallis)

Table 2.
The effect of combined plyometric training on strength, power, and speed

Group		Strength (kg)	Sig.	Power (W)	Sig.	Speed (s)	Sig.
CS	Pretest	44.09 \pm 21.30	0.000*	228.40 \pm 43.28	0.000*	5.15 \pm 0.26	0.000*
	Posttest	49.86 \pm 20.26		247.11 \pm 41.10		4.76 \pm 0.32	
TI	Pretest	41.77 \pm 12.57	0.000*	199.50 \pm 50.35	0.001*	5.26 \pm 0.29	0.000*
	Posttest	45.45 \pm 12.94		214.06 \pm 53.24		4.92 \pm 0.31	
ST	Pretest	54.32 \pm 22.18	0.000*	190.25 \pm 38.36	0.051	5.26 \pm 0.39	0.012
	Posttest	56.23 \pm 22.18		196.96 \pm 39.42		5.06 \pm 0.38	

All data were presented in mean and standard deviation (mean \pm SD)

CS: Continue board jump + skater hops; TI: Tuck jump + ins and outs; ST: Standard conventional training

* Significantly different between pretest and posttest ($p \leq 0.05$) (Wilcoxon signed rank test)

Performance test results (speed, power, and strength) were compared before and after six weeks of plyometric training (PT) in Table 2 and Figure 1. All groups showed a significant increase in strength, with $p = 0.000$. Combined plyometric and conventional training, administered to participants for six weeks, increased power in CS and TI by $p = 0.000$ and $p = 0.001$, respectively. Similar findings were observed for speed, where subjects in the treatment group showed the highest improvement in sprint time after performing board jump + skater hops ($p = 0.000$) and tuck jump + ins and outs ($p = 0.000$). As for the control group, there were no modifications in power that were considered to be statistically significant.

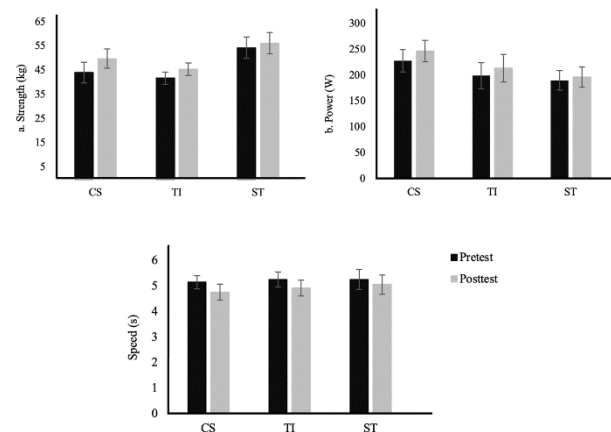


Figure 1. The comparison analysis of the mean score of strength (a), power (b), and speed (c) between groups. Data were presented in mean \pm SD.

Table 3.

Between-group differences on strength, power, and speed of muscle legs following six-weeks of plyometric training

Group	Δ Strength (kg)	%	Sig.	Δ Power (W)	%	Sig.	Δ Speed (s)	%	Sig.
CS	5.77 \pm 2.27	13.09		18.71 \pm 8.41	8.19		-0.39 \pm 0.37	7.57	
TI	3.68 \pm 1.48	8.81	0.000*	14.56 \pm 9.14	7.30	0.530	-0.34 \pm 0.35	6.46	0.492
ST	1.91 \pm 1.02	3.52		6.71 \pm 5.46	3.53		-0.20 \pm 0.36	3.80	

All data were presented in mean and standard deviation (mean \pm SD)

CS: Continue board jump + skater hops; TI: Tuck jump + ins and outs; ST: Standard conventional training

* Significantly different between groups ($p \leq 0.05$) (Kruskal-Wallis)

Table 3 presented the mean difference between groups on measured variables. The result of Kruskal-Wallis test disclosed the significant difference only in strength, where Δ strength in CS, TI, and ST were 5.77 ± 2.27 kg, 3.68 ± 1.48 kg, and 1.91 ± 1.02 kg ($p = 0.000$). Meanwhile, the changes in power and speed in all groups were found to be statistically the same ($p > 0.05$). Between three groups, CS showed greatest improvement in strength (13.09 %), power (8.19 %), and speed (7.57 %), while the smallest changes in all measured variables were found in ST which the subjects received conventional training.

Further analysis using Mann-Whitney disclosed the difference in strength between CS and ST ($p = 0.000$). Another pair which is ST and T was also found to be statistically different ($p = 0.020$), as stated in Table 4.

Table 4.

Post-hoc analysis of significant difference in strength

Group		sig.
CS	TI	0.007
	ST	0.000*
ST	TI	0.020*

CS: Continue board jump + skater hops; TI: Tuck jump + ins and outs; ST: Standard conventional training

Discussion

Prior research examining the impact of plyometric training on fitness and health has demonstrated that PT improves a number of health markers in addition to physical performance (Muthukumar & Sokkanathan, 2014). Plyometric trainings have been shown in nearly all studies to be more effective than other types of training in increasing muscular strength, power, flexibility, muscular endurance, and jumping ability (Bulqini et al., 2023; Putera et al., 2022). The current study showed that plyometric exercise for six weeks was beneficial in improving the strength, power, and speed of leg muscles. These results corroborate a prior randomized controlled trial (RCT) (Muthukumar & Sokkanathan, 2014) and experimental researches (Hariyanto et al., 2022; Putera et al., 2023) which demonstrated a significant difference in muscle strength between the plyometric training group and the control group. Recent study conducted by Wiriawan et al (2024) also found similar result where it has been observed that subjects practiced plyometric training showed notable improvement in leg's muscle strength before and after plyometric training was given, compared to the peers in the non-plyometric group.

These are some plausible explanations for why

plyometric training is able to increase strength. PT requires a proper technical skill and an adequate level of joint coordination and muscle strength, which then improves the contraction of inter-muscular and intra-muscular capacity, producing force (Hariyanto et al., 2022; Sáez-Sáez de Villarreal et al., 2010). The combination of two kind of plyometric trainings which were given to the experimental groups (continue board jump + skater hops and tuck jump + ins and outs) were able to shorten the change of extrinsic phase to concentric phase in faster time. It also escalates the ability to jump, supported by muscle ability to perform explosive moves resulting in the gain of strength and power in leg muscle (Louder et al., 2015).

According to a different study, adolescents who underwent plyometric exercise had improved strength performance in their dominant leg (Martel et al., 2005). The greater increase of muscle muscle strength and power were more apparent in U-17 participants when plyometric training was integrated with other exercises or trainings for lower and upper body. As indicated by multiple studies where PT was able to increase maximal strength from 11 kg to 60 kg when it was modified and combined with other training modalities (i.e. weight training + plyometric) (Sáez-Sáez de Villarreal et al., 2010), the combination of plyometric training with other exercise, such as weight training resistance training, is also found to be quite effective to increase power and strength (Chaouachi et al., 2017).

Additionally, the current study showed that the forward lateral leap and high hurdle jump might improve speed performance by roughly 13.09% for CS and 8.81% for TI. The study suggests that combination of two kinds of plyometric training for six weeks is sufficient to improve male students' 30-meter sprint performance. It confirms the findings of an earlier study that found football players' performance, particularly speed, was enhanced when plyometric training was mixed with a traditional training regimen (Manouras et al., 2016). These findings also support recent research that used various type of plyometric trainings and found that both young and adult participants' sprint performance improved (Manouras et al., 2016; Michailidis et al., 2013; Sedano et al., 2011). The enhancement of the sprint outcomes during plyometric exercise is associated with the stretch-shortening cycles (Huang et al., 2023). Similar results were obtained from earlier research on the effects of plyometric training on speed or velocity, which postulated that six weeks of PT would considerably enhance 10-, 30-, and 40-meter sprint

performances (Beato et al., 2018; Hariyanto et al., 2022). Studies that confirm the present study's findings about the positive benefits of PT on speed improvement have employed relatively similar training duration, lasting from five to eight weeks.

In contrast to this outcome, Ramirez-Campillo et al. found that performing drop jumping exercises twice a week for seven weeks did not statistically improve speed performance (Ramírez-Campillo et al., 2014). Moreover, Markovic et al. (2007) did not discover a speed enhancement in the 20-meter sprint. There are a number of reasons for the differences in results between the current and earlier research, but one that we have discovered may be related to the kind of plyometric training that was employed. Nonetheless, it is clear from all of the research on how PT affects speed performance that PT must be administered for at least five weeks in order to show a discernible increase in speed (Fischetti et al., 2018; Putera et al., 2019). This study backs up earlier studies showing that even brief duration of plyometric training can improve speed performance in young populations.

Conclusion

Strength and conditioning specialists have been using plyometric training extensively as a popular training strategy to improve physical performances. The results of this study allow us to draw the conclusion that students' strength, power, and speed are greatly increased when they get two distinct types of plyometric training for six weeks. Power increased in CS and TI as a result of combining plyometric and conventional training. Similarly, speed improvements were notable, with the treatment group demonstrating the greatest enhancements in sprint time after exercises like board jumps with skater hops and tuck jumps with ins and outs. In contrast, the control group did not exhibit any statistically significant changes in power. The study's narrow sample of student-athletes may limit the applicability of the findings to a more diverse population. In addition to that, plyometric training for longer duration may provide different outcomes.

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