

Examining the impact of contrast training protocols on vertical jump ability in varsity basketball players by inducing post-activation performance enhancement

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Published online: November 30, 2023

(Accepted for publication : November 15, 2023)

DOI:10.7752/jpes.2023.11344

Abstract:

Contrast training (CT) is a unique exercise approach that leverages post-activation potentiation (PAP) by integrating heavy and light loads while maintaining identical movement patterns within a single strength training. **Objective:** This study aimed to explore and compare the effects of post-activation performance enhancement (PAPE) using different contrast training protocols on vertical jumping performance. **Methodology:** Thirteen male varsity basketball players participating in this study were assigned in a counterbalanced randomized order to three contrast exercise sequences. Each protocol involved three distinct exercises: barbell back squat (BS) at 80% of 1-repetition maximum (1RM), weighted jump squat (WJ) at 20% 1RM, and band-assisted jump squat (BA) at 20 ± 5% of body-weight reduction (BWR). The contrast training 1 (CT1) involved 6 repetitions (reps) of BS followed by 12 reps of WJ. Contrast training 2 (CT2) consisted of 6 reps of BS followed by 12 reps of BA. Contrast training 3 (CT3) comprised three exercises: 6 reps of BS followed by 6 reps of WJ and 6 reps of BA. Peak power output (PPO), peak vertical ground reaction force (PVGRF), and peak barbell velocity (PBV) were assessed immediately following each CT program. **Results:** PBV and PVGRF significantly increased after CT1, CT2, and CT3 ($p < 0.05$). However, no significant differences were observed among the various contrast exercise conditions ($p > 0.05$). There were no significant differences in PPO immediately after the CT trial across the three conditions and between pre-post assessments ($p > 0.05$). Notably, significant differences in PBV were found among the three conditions ($p < 0.02$, partial $\eta^2 = 0.63$). Post-hoc analysis revealed that the PBV of CT2 was significantly better than that of CT1 and CT3. **Conclusion:** Our results indicate that CT is an effective method for enhancing jumping performance through the use of PAP during the preload exercise. The most significant improvement in jumping performance was observed with the combination of high-load resistance training followed by band-assisted jump squats. Therefore, coaches and athletes are encouraged to incorporate the CT method to enhance the jumping performance of basketball players.

Keywords: counter movement jump, muscle activation, power production, strength training

Introduction

Basketball requires muscular power to generate explosive force during activities such as jumping, sprinting, and changing direction (Brittenham, 1996; Gottlieb et al., 2021; Spiteri et al., 2014). This sport involves a unique set of skills executed in a dynamic motion context. Specifically, jumping ability plays a crucial role in basketball activities such as rebounding, blocking, and shooting. Consequently, lower limb muscles become a focal point in training regimens because the rate of force development depends on the power and speed of muscle contractions. Essentially, understanding the interplay between force and power production, coupled with sport-specific skills, is fundamental to the effectiveness of strength training in basketball (O'Brien et al., 2020; Zerk et al., 2019). Specifically, this involves the temporary enhancement of muscle power following a preceding contraction or exercise, a phenomenon known as post-activation performance enhancement (PAPE) (Blazevich & Babault, 2019; Hodgson et al., 2005). Several studies have demonstrated that PAPE can improve sport performance by improving power, sprinting, and jumping abilities (Brink et al., 2022; García-Pinillos et al., 2014; Latorre Román et al., 2018). PAPE achieves this by enhancing motor unit recruitment through neuromuscular adaptations, leading to a temporary performance boost in subsequent activities (Docherty et al., 2004; Sweeney et al., 1993).

Contrast training (CT) is a hybrid training method that incorporates a series of exercises involving both high-loads and light-loads with the same movement action within a single strength session. CT leverages PAPE to enhance force, power production, jumping ability, and sprint performance (Baker, 2001; Baker, 2003; Hammami et al., 2019; Schneiker et al., 2018; Smilios et al., 2005). One of the most well-known instances of CT involves combining high-load squats with plyometric exercises such as jump squats. When comparing these two movements, both entail vertical propulsion and similar lower body actions through triple extension/flexion at the hips, knees, and ankles (Banks, 2016). High-load squats recruit a substantial number of muscle fibers and stimulate the nervous system. On the other hand, plyometric training (PT) engages the stretch-shortening cycle (SSC), defined as the transition from a high-velocity eccentric muscle action immediately followed by a

powerful concentric muscle contraction. This cycle contributes to enhancing the rate of force development (RFD) and maximal power production (McBride et al., 2002; Wagner & Kocak, 1997; Winchester et al., 2008). More recently, PT with assistance (reduced load) or resistance (increased load) has garnered increased interest (Argus et al., 2011; Khodaei et al., 2017; Stien et al., 2020). In theory, incorporating assistance or resistance to the athlete's body mass can lead to faster muscle contractions or the generation of a greater initial force (Makaruk et al., 2020; Markovic et al., 2011; Strate et al., 2022).

Resisted PT primarily enhances performance by increasing muscle force for lower-velocity movements, whereas assisted PT could potentially result in performance improvement due to high-velocity movements (Argus et al., 2011; Sheppard et al., 2011). A study by Rosas et al. (2016) found that loaded jumping resulted in greater improvements in both vertical and horizontal jump performance than unloaded jumping because the additional load induced a higher ground reaction force and impulse. While resisted jumping utilizes added load to achieve high power, assisted jumping employs the overspeed concept. In this approach, an assistive device aids in propelling the participant off the ground, requiring muscle adaptation to accommodate the heightened take-off velocity. A study by Argus et al. (2011) comparing jump performance among assisted, resisted, and free jumping found that assisted jumping improved peak velocity by approximately 37% compared to resisted jumping and by approximately 6% compared to free jumping. This enhancement in peak velocity during assisted jumping was attributed to a more effective improvement in the stretch reflex rate (Sheppard et al., 2011). To our knowledge, this is the first study to analyze the immediate effects of PAPE involving a combination of high-load squat training with assisted and resisted plyometric training to augment jumping performance. Further investigation is warranted to establish more definitive evidence regarding the effectiveness of these combinations. Consequently, the objective of this study was to evaluate the impact of post-activation performance enhancement through various CT methods on jumping performance in varsity basketball players. We hypothesized that different combinations of CT methods, specifically the integration of high-load squat training with assisted and resisted jumps, would enhance jumping performance among varsity basketball players.

Materials and methods

Participants

Thirteen male varsity basketball players, with a mean age of 21 ± 1.6 years, mean height of 183.46 ± 7.99 cm, mean body mass of 78.16 ± 11.27 kg, and a mean relative strength of 1RM back squat of 1.74 ± 0.21 kg/body mass, were recruited for this study via purposive sampling. The inclusion criteria were an age range of 18–25 years. The participants had to have at least two years of experience in national university basketball competitions and prior experience in resistance training, specifically involving the back squat exercise. The participants were required to execute a back squat (BS) with a load of $\geq 1.5 \times$ body weight, maintaining a knee flexion of at least 110° , and had to be free from current musculoskeletal injuries. All study participants were informed of the study's purpose and procedures and signed an informed consent form. The study protocol was approved by the Ethics Review Committee and adhered to the principles outlined in the Declaration of Helsinki regarding research involving human subjects.

Data collection

1-repetition maximum (1RM) measurement

The 1RM back squat was evaluated to determine an appropriate exercise intensity for each intervention. The participants performed a standard warm-up, which included 5 min of stationary cycling at 50% of the heart rate reserve (HRR), followed by 10 bodyweight squats. Subsequently, they performed 6 repetitions at 50%, 4 repetitions at 70%, and 1 repetition at 80% of the estimated 1RM. The 1RM back squat was assessed following the protocol outlined by McBride et al. (1999); specifically, the participants started lifting at 85% of the estimated 1RM, with the load progressively increased until they reached their limit. In the back squat exercise, the participants were instructed to lower themselves to a knee angle of approximately 110° . To ensure consistency, a rope was employed to guide the participants, ensuring a knee angle of 110° . The participants were required to touch their posterior thighs to the rope during the downward movement before being allowed to ascend. A metronome, set at 60 bpm, was employed to regulate a 2-s eccentric and 1-s concentric tempo (2-0-1). Rest periods of 3–5 min were implemented between maximum attempts.

Jumping performance test

Jumping performance was evaluated using the counter movement jump (CMJ) with a power cage (FT 700 Power System; Fitness Technology, Adelaide, SA, Australia) and the Ballistic Measurement System software (Innervations, West Perth, Western Australia). Each participant initiated the CMJ from a standing position with an unloaded bar in a balanced position on the upper back and shoulders. The participants were instructed to drop into the squat position at a 110° knee flexion and then promptly execute a vertical jump with no arm swing, aiming to reach maximum height. In addition, the participants were required to take off with both feet and perform the maximal jump in three attempts, with a 90-s rest period between each jump. The best result from the CMJ was utilized for subsequent analysis.

Vertical ground reaction force (VGRF) was recorded using a force platform (400 Series; Fitness Technology) at a rate of 200 Hz with 20-s sample periods. Velocity was derived from the displacement data with respect to time (calculated based on the sampling frequency) to obtain instantaneous velocities throughout the

jump squat. Power was determined as the product of VGRF and barbell velocity, following the methodology of Dugan et al. (2004). The following parameters—peak power output (PPO), peak vertical ground reaction force (PVGRF), and peak barbell velocity (PBV) were expressed as percentages of PAP. PAPE is defined as a short-term improvement in performance induced by maximum muscle activation (Boullosa et al., 2020). The following equation was used to calculate PAPE.

$$\text{PAPE (\%)} = \frac{\text{Performance during post-test}}{\text{Performance of pretest}} \times 100$$

where values <100 indicate no PAPE, and values >100 indicate PAPE (Cleary & Cook, 2020).

Experimental protocols

The experimental procedure aimed to examine the immediate effects of three CT methods (CT1–3) during a pre-season training program. The participants were directed to attend the laboratory at the same time on five separate occasions within one week (Fig.1). During the first visit, the participants were tested for 1RM back squat, while the second visit served as a familiarization session where the participants were asked to perform weighted jump squats (WJ) and band-assisted jump squats (BA). For these exercises, an elastic band was attached at hip level for each participant.

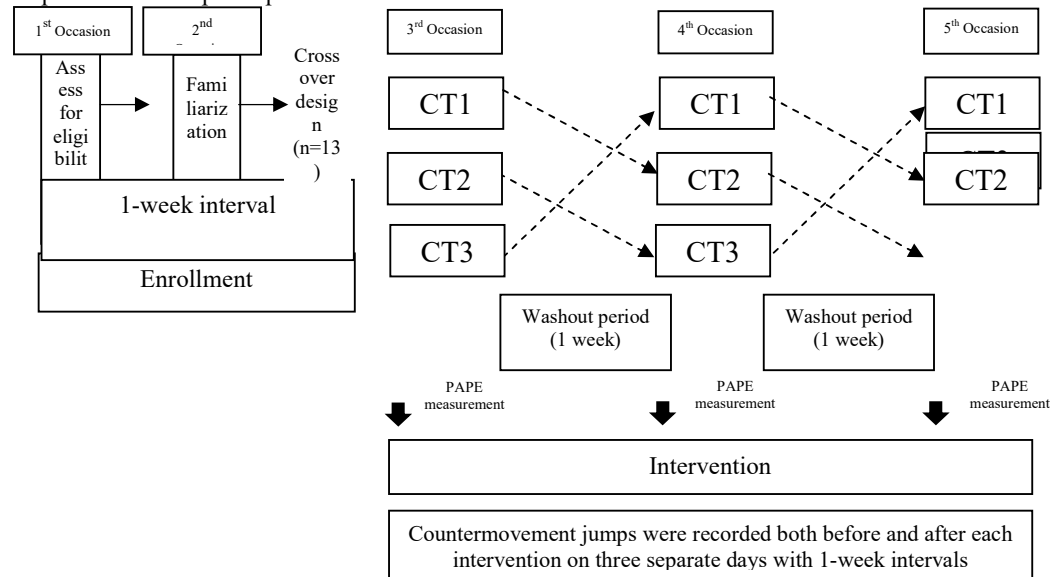


Figure 1. Flow chart of the study design

The participants were randomly assigned to complete three different CT programs, employing a counterbalanced design for the subsequent three visits. The three CT programs were as follows: CT1 involved 6 reps of BS followed by 12 reps of WJ with a 30-s rest between exercises; CT2 consisted of 6 reps of BS followed by 12 reps of BA with a 30-s rest between exercises; CT3 included 6 reps of BS followed by a 15-s rest, followed by 6 reps of WJ at 20% 1RM with another 15-s rest, and concluded with a set of 6 reps of BA (Fig. 2). The participants were instructed to avoid strenuous exercise for 24 h before the intervention. All participants underwent a 5-min warm-up comprising cycling exercise at 50% of HRR, along with 10 bodyweight squats and 10 squat jumps.

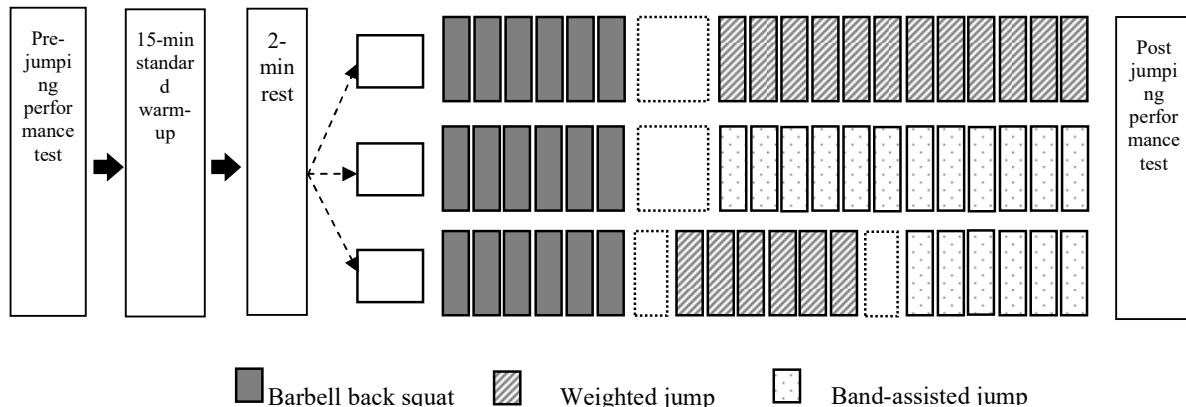


Figure 2. Contrast training structure protocols

* BS = barbell back squat at 80% of 1RM; WJ = weighted jump squat at 20% of 1RM; BA = band-assisted jump squat at 20 ± 5% body weight reduction; s = seconds

Statistical analysis

The data were presented as the mean $\pm$ standard deviation with 95% confidence intervals (CIs). Normal distribution was verified using the Shapiro–Wilk test. A mixed analysis of variance [ANOVA: group (CT1, CT2, and CT3) $\times$ time (pretest and post-test)] was used to assess the main and interaction effects on PPO, PVGRF, and PBV. If a significant difference was detected, post hoc tests with Bonferroni correction were conducted for pairwise comparisons. Furthermore, differences in the percentage of post-activation performance enhancement for jumping performance variables were evaluated using repeated measure one-way analysis of variance with Greenhouse–Geisser correction. Effect sizes (ES) were computed using Cohen’s *d* (Cohen, 1988), classified as small ($d < 0.50$), medium ($0.50 \leq d < 0.80$), and large ($d \geq 0.80$). A probability (*p*) value of <0.05 was considered statistically significant. All statistical analyses were performed using IBM SPSS Statistics for Windows, version 23.0 (IBM Corporation, Armonk, NY, USA).

Results

Table 1 presents the results of jumping performance before and after the CT interventions. No significant differences in PPO were observed immediately after the CT trial across the three conditions and between the pre- and post-intervention assessments ($p > 0.05$). The mixed ANOVA analysis revealed a significant main effect of time on PVGRF ($p < 0.01$, partial $\eta^2 = 0.84$), but no significant interaction (intervention $\times$ time) was observed ($p > 0.05$). Furthermore, a significant main effect of time was identified for PBV ($F(1, 12) = 79.117$, $p < 0.01$, partial $\eta^2 = 0.87$). PBV values after CT1, CT2, and CT3 were 2.59 ± 0.25 , 2.94 ± 0.40 , and $2.72 \pm 0.13 \text{ m s}^{-1}$, respectively. No significant differences were observed among the contrast exercise conditions ($p > 0.05$). The results indicated a significant interaction effect on PBV ($F(2, 24) = 36.155$, $p < 0.01$, partial $\eta^2 = 0.84$). Nonetheless, changes in the mechanical parameters of jumping performance also provided valuable insights into the effectiveness of the CT intervention, demonstrating a positive response. Additionally, Table 2 shows the percentage of PAPE in jumping performance variables after the three CT conditions. The results revealed no significant difference in %PAPE calculated from PPO ($p = 0.204$) and PVGRF ($p = 0.485$) among the three methods. However, the %PAPE of PBV exhibited a statistically significant difference ($p < 0.01$, partial $\eta^2 = 0.63$). A post hoc pairwise comparison using the Bonferroni correction indicated an increase in the %PAPE of PBV for CT2 compared to that after CT1 and CT3. Moreover, there was a significant difference in the %PAPE of PBV between CT2 and CT3 ($p = 0.01$).

Table 1. Jumping performance outcomes for three interventions before and after contrast training trials

Variables		CT1 (n = 13)			CT2 (n = 13)			CT3 (n = 13)			Group effect s	Time effects	Group $\times$ time effect s
		Mean $\pm$ SD	CV %	95% CI	Mean $\pm$ SD	CV %	95% CI	Mean $\pm$ SD	CV %	95% CI			
PPO (w)	Pre	4120.47 ± 995.42	24.1 6	(3518.95, 4722.00)	4141.09 ± 946.6	22.8 6	(3569.09, 4713.09)	4152.17 ± 89.34	19.0 1	(3675.18, 4629.16)	0.14	0.23	0.49
	Post (PAP)	4352.96 ± 831.42	19.1 4	(3850.54, 4855.38)	4687.87 ± 80.72	16.6 5	(4216.09, 5159.65)	4532.48 ± 42.08	16.3 7	(4084.05, 4980.92)			
PVGRF (Nm)	Pre	2007.63 ± 346.18	17.2 4	(1798.43, 2221.68)	1971.74 ± 300.07	15.2 2	(1790.41, 2153.07)	2029.30 ± 358.05	17.6 4	(1812.94, 2244.56)	0.19	0.00*	0.49
	Post (PAP)	2110.88 ± 351.29	16.6 4	(1898.60, 2322.31)	2000.42 ± 290.31	14.5 1	(1824.99, 2175.85)	2081.52 ± 365.00	17.5 4	(1860.95, 2302.08)			
PBV (m s ⁻¹)	Pre	2.53 ± 0.25	9.76	(2.38, 2.68)	2.51 ± 0.47	18.7 7	(2.22, 2.79)	2.54 ± 0.12	4.6	(2.47, 2.61)	0.52	0.00*	0.00*
	Post (PAP)	2.59 ± 0.25	9.71	(2.43, 2.74)	2.94 ± 0.40	13.4 3	(2.71, 3.18)	2.72 ± 0.13	4.63	(2.65, 2.80)			

*($p < 0.05$), CT: contrast training; CT1: BS+WJ; CT2: BS+BA; CT3: BS+WJ+BA; BS: barbell back squat; WJ: weighted jump squat; BA: band-assisted jump squat; CV: coefficient of variation; CI: confidence interval

Table 2. Comparisons of %PAPE among the three CT methods

PAPE (%)	CT1 (n = 13)			CT2 (n = 13)			CT3 (n = 13)			F	p	Effect size
	Mean ± SD	CV%	95% CI	Mean ± SD	CV%	95% CI	Mean ± SD	CV%	95% CI			
PPO	107.69 ± 10.92	10.14	101.75, 113.62	115.58 ± 15.15	13.10	107.34, 123.81	110.17 ± 9.56	8.67	104.97, 115.36	1.768	0.20	0.13
PVGRF	105.37 ± 6.84	6.49	101.65, 109.08	101.65 ± 4.21	4.14	99.36, 103.93	102.96 ± 10.25	9.99	97.38, 108.53	0.696	0.49	0.55
PBV	102.17 ± 2.79	2.73	100.65, 103.68	119.14 ± 12.67 β ‡	10.63	112.25, 126.02	107.39 ± 3.22 ‡	2.99	105.64, 109.14	20.185	0.00	0.63

*(p < 0.05) CT: contrast training; CT1: BS+WJ; CT2: BS+BA; CT3: BS+WJ+BA; BS: barbell back squat; WJ: weighted jump squat; BA: band-assisted jump squat; β: significant difference between CT2 and CT3; ‡: significant difference from CT1 (p < 0.05); CV: coefficient of variation; CI: confidence interval

Discussion

The aim of this study was to compare the effects of PAPE on vertical jump performance using three CT methods (CT1: BS+WJ; CT2: BS+BA; CT3: BS+WJ+BA). The key finding was that PAPE induced by CT, particularly with a combination of high-load barbell back squat and band-assisted jump squat (CT2), resulted in the most substantial acute improvement in PBV compared to other contrast training methods (CT1 and CT3). These findings substantiate our hypothesis that different combinations of CT methods would enhance jumping performance. In this study, CT2 increased PBV by approximately 19%, whereas CT1 and CT3 increased PBV by approximately 2% and 7%, respectively. Consistent with prior research, the mechanism of PAP likely contributed to the enhanced jumping performance through neuromuscular adaptations facilitated by the high-load resistance of the preload activity.

The engagement of higher-order motor units and the phosphorylation of the myosin light chain, induced by weight lifting at maximal or sub-maximal intensity, lead to an increase in sarcoplasmic Ca^{2+} (Tillin & Bishop, 2009; Hodgson et al., 2005). Notably, the results indicate that CT2 and CT3 incorporating BA facilitated rapid muscle contractions by reducing the effective mass of the jumper and increasing velocity during the jump (Markovic et al., 2011; Sheppard et al., 2011). BA enhances the strength-shortening reflex, promoting accelerated vertical jumps with full extension of hips, knees, and ankles, thereby contributing to improved force and velocity development (Haff, 2012; Chu, 1996). Furthermore, BA is a superior technique for enhancing jump ability by reducing body weight and ground contact time (Markovic & Jaric, 2007; Markovic et al., 2011; Sheppard et al., 2011). This discovery aligns with a study by Tran et al. (2011) where the utilization of an elastic band, decreasing body weight, and ground contact time, led to an increase in takeoff velocity. According to our study, CT2 induced the most substantial improvement in the PAPE of PBV compared to CT1 and CT3 (F = 20.185, p = 0.00). These findings are consistent with several studies indicating that assisted jumps significantly enhance jump height and peak velocity compared to resisted jumps (Imachi et al., 1997; Markovic & Jaric, 2007; Tran et al., 2011; Vuk et al., 2012). Assisted jumps employ an "overspeed" approach, enabling participants to attain a greater takeoff velocity and facilitating muscle adaptation to accommodate higher limb velocity than free jumping. The combination of high-load weight training and band-supported jump squats within the same session enhanced the synergistic effect, thereby benefiting power and acceleration abilities (Chu, 1996). These findings corroborate earlier studies demonstrating that combined training contributes to improved muscular power (Kotzamanidis et al., 2005; Krémár et al., 2021; Mitchell & Sale, 2011; Tricoli et al., 2005; Zghal et al., 2019). Interestingly, CT2 exhibited the most substantial percentage change in PPO by approximately 15%, compared to CT1 and CT3 (~7% and ~10%, respectively). This difference can be attributed to CT2 eliciting the greatest improvement in PBV compared to CT1 and CT3 (F = 20.185, p = 0.00). However, no significant differences were observed in PVGRF between interventions.

CT1 attained the highest PVGRF by approximately 5%, likely due to the impact of weighted jumping in inducing force and enhancing the rate of force development. Resisted jumping enhances the power of the body to quickly move against an external load. These outcomes align with the findings of Argus et al. (2011), where resisted jumping resulted in greater peak VGRF and vertical jump displacement. Consequently, PVGRF was superior with CT1, indicating enhanced neural activation compared to CT2 and CT3. The results of this study underscore the effectiveness of an innovative CT approach that combines high-load weight training with BA, resulting in a significant increase in PBV, relative peak VGRF, and power. This, in turn, contributes to a greater vertical jump displacement. Our study underscores the importance of implementing CT for athletes engaged in sports that demand jumping, sprinting, and explosive lower-body movements, particularly in the case of basketball players relying on vertical jumping for rebounds, blocks, and shots. Future research in this area should focus on the acute effects of CT using a combination of high-load weight training and assisted sprints to

optimize power, movement velocity, and speed performance. However, it is crucial to acknowledge certain limitations in this study. The inclusion of only male athletes may limit the generalizability of our findings, highlighting the need for future studies to encompass female professional or elite athletes. Additionally, we recommend considering comparable height and weight as inclusion criteria. Furthermore, addressing these limitations and ensuring larger sample sizes will be essential for a comprehensive exploration of the influence of CT methods on jumping performance.

Conclusions

In summary, this study revealed a significant improvement in jump performance, especially when employing a combined band-assisted plyometric exercise following high-load resistance training. This approach led to a significant increase in peak barbell velocity, indicating its efficacy in enhancing the velocity of vertical jumps in basketball players. Although certain metrics did not exhibit significant differences, the overall mechanical parameters of jumping performance indicated a positive response to the CT interventions. Our investigation suggests that CT is a valuable method for enhancing jumping performance through PAP during the preload exercise. Consequently, coaches and athletes are encouraged to consider integrating the CT method into training regimens to enhance the jumping performance of basketball players.

Acknowledgments

The authors extend their gratitude to all participants from Chulalongkorn University Basketball Club for their valuable contributions to this study. Finally, the authors would like to thank Falcon Scientific Editing (<https://falconediting.com>) for proofreading the English language in this paper.

Conflicts of interest

The authors declare no conflicts of interest.

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