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A combination of ballistic exercises with slow and fast stretch-shortening cycle induces post-activation performance enhancement

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Abstract
Introduction. **The stretch-shortening cycle (SSC) ability of a muscle is responsible for sprinting and changing direction during sports activity. Sprinting involves more fast SSC ability while a change of direction (COD) requires both fast and slow SSC. Post-activation performance enhancement (PAPE) is an acute enhancement of muscular performance due to previous muscular contraction. Heavy resistance exercises and plyometric exercises are commonly used PAPE method, utilizing either slow or fast SSC activity for inducing PAPE.** Aim of Study. **This study aimed to examine the effect of a combination of ballistic exercises (BE) with slow and fast SSC on sprint and COD ability.** Material and Methods. **In a randomized crossover manner, 12 male university basketball players (age 21 ± 1.2 years; height 170 ± 8 cm; body mass 66.8 ± 7 kg; fat percentage (%) 10.2 ± 2.4) performed 3 × 5 repetitions of a combination of box jump and immediate drop jump (BDJ) or walking control after a standard warm-up protocol. A baseline measurement was recorded 1 minute after warm-up and post-measurement after 3 minutes of interventions.** Results. **Significant large improvement in COD performance was observed after BDJ compared to baseline ($p < 0.001$, $d = 0.982$) and controlled conditions (interaction effect; $p = 0.006$, partial $\eta^2 = 0.518$). While, no improvement was found in 15 m sprint performance with baseline ($p = 0.282$, $d = 0.285$) or controlled conditions (interaction effect; $p = 0.649$, partial $\eta^2 = 0.020$).** Conclusions. **The results of the study suggest that warm-up followed by a BDJ protocol induces PAPE effect and improves COD performance.**

KEYWORDS: modified agility T-test, 15 m sprint, BDJ, box jump, drop jump, SSC.

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Introduction

Basketball is a sport that involves many diverse activities like acceleration, deceleration, and COD during the game in response to an opposing player or ball movement [38]. It requires players to be exceptional in multidirectional movements such as forward, backward, and lateral sprints [35]. Modified agility T-test (MAT) is a modification of the T-test and is a reliable test for assessing change of direction ability of basketball players, as it includes forward, lateral, and backward movements [35]. Although T-test is a widely used agility test, it does not entirely replicate movement patterns involved in field or court sports. The total sprinting distance covered in T-test is approximately 40 m while the mean distance of sprints during field or court sports is between 10 and 20 m [2]. MAT involves a total distance of 20 m and thus replicates the requirements of field or court sports [35].

Warm-ups are performed before sports or activity to attain optimal performance [27] and prevent injuries by increasing muscle temperature, nerve conductivity, metabolic reactions [4], blood flow, elevated oxygen consumption, and PAPE [17]. PAPE is an acute enhancement of muscle performance measured through maximal strength, power, and speed following a conditioning activity/contraction [34] performed intending to maximize movement velocity [11]. PAPE based warm-ups have shown to produce a small increase in jump performance and a large improvement in sprint performance compared with control or other warm-up activities [16].

Previous studies have suggested different forms of heavy resistance exercise to induce PAPE in athletes, which may not be feasible due to practical and logistical considerations [23, 29]. Maloney et al. [24] suggested that BE if implemented correctly can be an alternative to high resistance exercises since maximal motor unit recruitment can also be achieved with these exercises. BE involves either a jumping action where the body leaves the ground or a throwing action where the projectile leaves the hand. Box jump and drop jump are both BE, with slow and fast SSC involvement due to their contraction time before the jump [36]. Combining different BE with fast and slow SSC characteristics may benefit activating the muscle fibers in different ways, due to different visco-elastic properties possessed by fast and slow-twitch muscle fibers [6].

The effect of a combination of slow and fast SSC activity as in BDJ on the PAPE effect has not been studied. Box jump involves a countermovement jump onto the box. While a drop jump is attempted by dropping from the box and attempting an immediate vertical jump for maximum height after landing on the ground. Unlike other PAPE methods, whose practical implementation may be limited due to cost, or safety concerns, and may not be afforded by teams or athletes with a limited budget. In such cases, BDJ may be beneficial due to its cost-effectiveness feature requiring only a box to perform the protocol. This study investigates the acute effect of a BDJ protocol after a warm-up on MAT and 15 m linear sprint test performance.

Aim of Study

The aim of this study was to find the effect of a combination of fast and slow SSC on acute performance enhancement of (a) 15 m linear sprint and (b) modified agility T-test (change of direction ability).

Material and Methods

Subjects

A total of 18 subjects agreed to participate in the study and were present during the familiarization and anthropometric measurements. 12 subjects (Mean ± SD; age 21 ± 1.2 years; height 170 ± 8 cm; body mass 66.8 ± 7 kg; fat percentage (%) 10.2 ± 2.4) completed the study (Table 1). The study was conducted during the off-season after completion of the university games. Inclusion criteria for the study were the absence of major lower limb injury in the past 6 months, any other recent injury, or neuromuscular disorder which could potentially limit performing sprints and jumps. Subjects reported participation in plyometric training in the past. After the explanation of the procedures, players signed the informed consent form, confirming their voluntary participation in the study. This study was approved by the Departmental Research Committee of the Institute and conducted following the Declaration of Helsinki.

Table 1. Subject characteristics

Participants (n = 12)	Mean ± SD	Range
Age (years)	21 ± 1.2	19-23
Height (m)	1.7 ± 0.8	1.6-1.9
Body Mass (kg)	66.8 ± 7	54.3-75.3
Fat Percentage (%)	10.2 ± 2.4	7.4-14.7
BMI (kg/m^2)	22.1 ± 1.4	19.5-23.9

Experimental approach to the problem

A within-subject randomized crossover design with a controlled condition was used to investigate the effect of BDJ protocol after a warm-up on MAT and 15 m linear sprint performance. The participants were evaluated on 2 separate days in a randomized crossover manner with a minimum interval of 48 hours between sessions to avoid carry-over effect. Both sessions were conducted in the same period of the day (11.00 to 13.00) to minimize the circadian effect on performance. Each subject followed a 10-minute warm-up protocol followed by baseline assessments. After 3 minutes of baseline assessments, subjects either performed BDJ protocol or walked for 3 minutes (Figure 1). The post-intervention assessment was done at approximately 3 minutes, as the PAPE during BE has been observed with recovery duration ranging from 1 to 3 minutes [24]. Randomization was carried out using an online randomization tool (www.randomizer.org). The assessment protocol included MAT and 15 m linear sprints in a sequential order to maintain consistency throughout assessments, and minimize any possible fatigue effect among variables. All assessments were carried out in a synthetic basketball court by the same researchers who were blind to the allocation of intervention throughout the study.

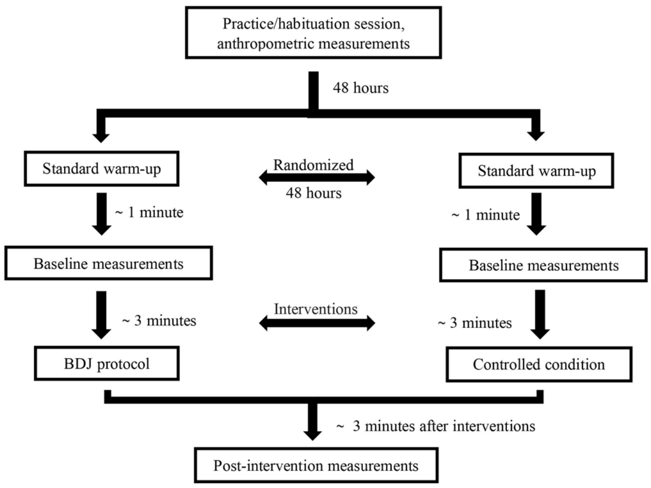

Figure 1. A schematic diagram of the design followed in the study

Procedure

One familiarization session was conducted for the participants with the BDJ and test protocols to avoid possible interferences in the results as a function of learning and coordination of movements. Players' fitness characterization by anthropometric measures was obtained the same day. Height, body mass, and body fat percentage were recorded (Table 1). The mean daily temperature during data collection was 28°C (82.4°F). The participants were asked to avoid alcohol for 24 hours, caffeine for 6 hours, food for 3 hours before the assessment, and any strenuous exercise 24 hours prior, or between the assessment days.

On the assessment day, the subjects first underwent a 10-minute warm-up, followed by baseline assessment, PAPE intervention or controlled condition, and post-intervention assessment. Warm-up started with dynamic stretching exercises in a full kinematic range for hamstrings, quadriceps, adductors, hip flexors, and soleus. It was followed by jogging, COD runs, repeated sprints, acceleration sprints, and line drill (Table 2).

BDJ protocol

A box of 0.65 m height was used for the study since a drop height of 0.65 to 0.72 m were found to have maximum jump height without the influence of leg strength [41]. BDJ was performed by jumping onto the box after a countermovement and then dropping from the box with an immediate vertical jump with minimum ground contact time (Figure 2). Subjects performed 3 sets of 5 BDJ repetitions with a rest period of 10 seconds between repetitions and 60 seconds between sets.

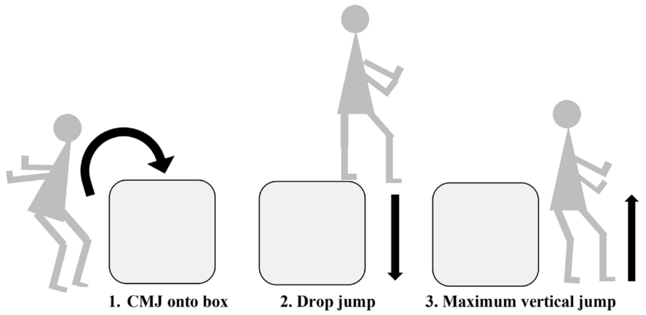

Figure 2. Diagram of BDJ exercise which includes a CMJ onto the box and an immediate drop jump

Modified agility T-test and 15 m linear sprint test

MAT was used to determine the speed with directional changes, which included forward sprinting, left and right shuffling, and backward running (Figure 3). The test was administered according to the guidelines set by Sassi et al. [35]. A pair of single beam photocell timing system (Cronox, Madrid, Spain) was placed at the start/finish line.

15 m linear sprint test was used to determine the acceleration speed and assessed using two pairs of

Table 2. The warm-up protocol followed in the study

Sl. No.	Activity with description	Duration	Repetitions	Rest interval
1	Dynamic stretching: exercises in a full kinematic range for hamstrings, quadriceps, adductors, hip flexors, and soleus	2 minutes		
2	Jogging: continuous jogging at submaximal intensity	3 minutes		
3	Shuttle runs: each shuttle run repetition consist of 3 COD runs from baseline to free throw line	2 minutes	3 × 5.8 m	15 sec
4	Acceleration sprints: sprints from the baseline up to center line	2 minutes	3 × 14 m	15 sec
5	Line drill: start from the baseline, touch every horizontal line of the court (i.e. free throw line of backcourt, center line, free throw line of frontcourt and baseline of other side), and finish on the starting baseline	1 minute	1	

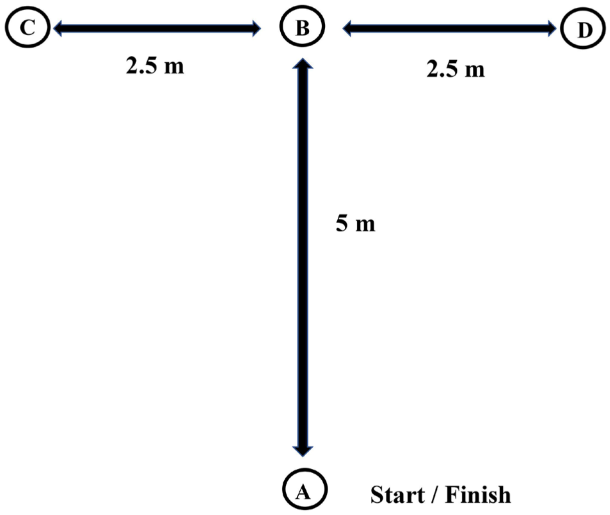

Figure 3. Modified agility T-test. The subject runs forward from A to B, then shuffles to C, then shuffles to the right to D, then shuffles back to B, before running backward to the start/finish line at A

photocell timing system (Cronox, Madrid, Spain) placed 15 m apart. In both MAT and 15 m sprint test, the photocell timing system were placed at a height of 0.6 m and subjects started 0.5 m behind the first photocell and were instructed to begin with their preferred foot forward on a line marked on the floor from a standing position. Two trials were conducted for each test with a rest period of 1 minute between each trial and test [32]. The best timing was selected for analysis.

Statistical analysis

Data were analyzed using IBM SPSS (version 20.0.0) and presented as Mean ± SD. Shapiro–Wilk test approved the normality of the data. A two-way (2 × 2) repeated measures ANOVA with time (baseline and post-intervention assessments) and interventions (BDJ and control) as within-within subject factors were used for analyses. The interaction effect between time and intervention was used for finding the effectiveness of the BDJ protocol. A paired T-test was conducted to observe differences between baseline and post-assessment. The effect size of the interaction effect was calculated using partial η^2 with 0.01 defining small, 0.06 medium, and 0.14 large effect. Cohen d were calculated for baseline and post-assessment difference with 0.20 defining small, 0.50 defining medium, and 0.80 defining large effect sizes. The level of significance for all tests was set at 0.05.

Results

Two-way repeated-measures ANOVA revealed significant interaction effect (time × intervention: $p = 0.006$, partial $\eta^2 = 0.518$) in MAT with a large effect size (Figure 6). MAT performance was also significantly higher ($p < 0.001$, $d = 0.982$) after BDJ protocol than baseline. No significant interaction effect was found in the 15 m linear sprint test (Table 3).

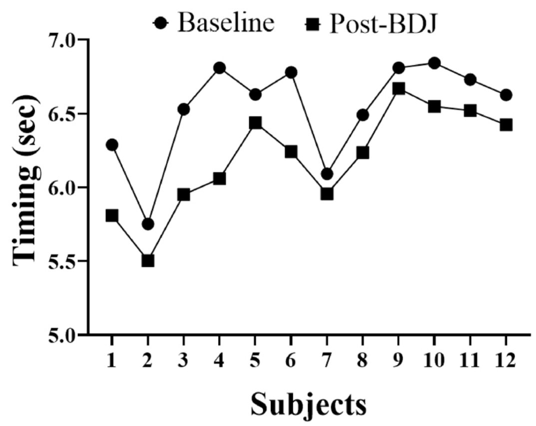

Figure 4. Graphical representation of the individual performance of MAT during baseline and post-intervention using the BDJ protocol

Table 3. Baseline and post-intervention scores of MAT and 15 m sprint of subjects during BDJ and controlled condition

	Intervention	Baseline Mean ± SD	Post-intervention Mean ± SD	P-value With baseline	E.S. (d) With baseline	P-value Interaction	E.S. (η^2) Interaction
MAT (sec)	BDJ	6.532 ± 0.335	6.197 ± 0.348	<0.001 †	0.982	0.006 ‡	0.518
	CON	6.205 ± 0.24	6.311 ± 0.307	0.267	0.384		
15 m sprint (sec)	BDJ	2.491 ± 0.075	2.508 ± 0.069	0.282	0.245	0.649	0.020
	CON	2.487 ± 0.088	2.494 ± 0.099	0.549	0.079		

Note: MAT – modified agility T-test, BDJ – box and drop jump, CON – controlled condition, E.S. – effect size, d = Cohen d, η^2 – partial eta square, † significant difference compared with baseline; ‡ significant interaction effect between BDJ and control condition

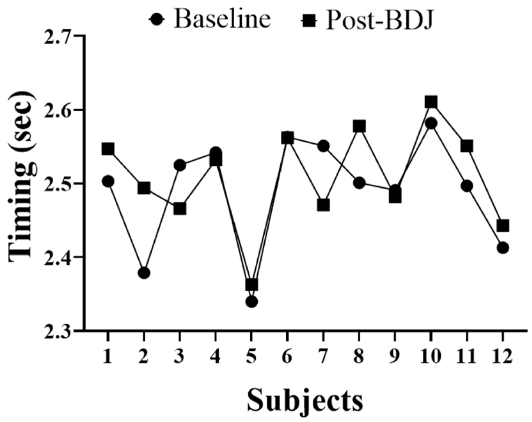

Figure 5. Graphical representation of the individual performance of the 15 m linear sprint test during baseline and post-intervention using the BDJ protocol

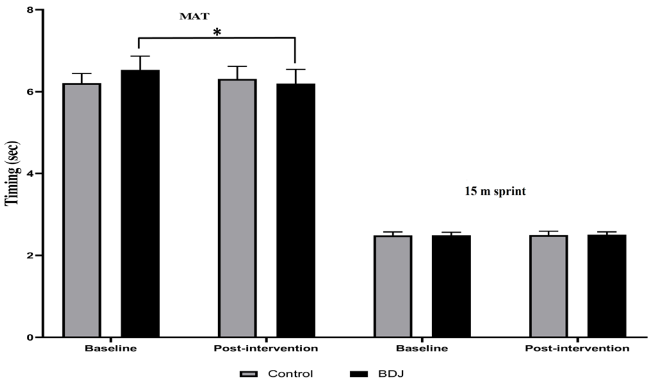

Figure 6. Mean ± SD of MAT and 15 m sprint performance

Discussion

The study aimed to find a PAPE effect through a combination of slow and fast SSC activity (BDJ) on MAT and 15 m linear sprint ability of university basketball players. The study demonstrated BDJ as an effective method of inducing PAPE during MAT compared with a controlled condition and within-condition baseline assessment. The findings suggest that performing BDJ after warm-up is highly effective in acute improvement of MAT performance as large effect sizes were observed in the interaction and within condition effect.

Different PAPE protocols have been used earlier to augment power production in athletes from varying sports, but the limitation of all those PAPE methods was the need for heavy loading using equipment, which is costly and has logistical as well as safety considerations. This led researchers to find alternative ways of inducing PAPE and overcoming those limitations. To the authors' knowledge, plyometric exercises using alternate-leg bounding [44], drop jump based on vertical or horizontal components [5, 7, 12], and a combination of ankle hops, hurdle hops, and drop jumps [20] have been studied for inducing PAPE in athletes. The above studies reported that a very heavy loading preload stimulus is not necessary for inducing PAPE. Our study supports these findings, as BDJ including 3 sets of 5 repetitions is found to be sufficient in inducing PAPE during MAT. Previous studies by Petisco et al. [32], Maloney et al. [25], and Okuno et al. [30] support our finding of BDJ inducing PAPE during MAT. These studies used external weight, ranging from 5% to 10% body mass during warm-up [25], and 50% to 90% of 1 RM back squat [30, 32] as conditioning activity which may put an unconditioned athlete at risk of getting injured. On the other hand, the use of BDJ protocol is safer than its heavy resistance counterparts such as 80% or 90% of 1 RM back squat, while also being cost-effective. As per the authors' knowledge, very few studies have been conducted on the effect of conditioning activity inducing PAPE during the change of direction ability. Lack of studies of PAPE effects on COD ability using plyometric exercises limits the authors to make other possible comparisons.

Lack of electromyography recording has been a limitation to this study, but the PAPE effect has been continuously linked with maximal activation of the muscles involved during the activity and is a key component in inducing PAPE [44]. Maloney et al. [24] suggested that the correct implementation of BE can be a substitute for high resistance exercise since BE also seeks to achieve maximal motor unit recruitment without heavy and expensive equipment. BE is characterized by jumping or throwing actions, where either the body leaves the ground or a projectile leaves the hand. In a BE, the braking phase found in traditional resistance exercise is eliminated, which increases the relative duration of positive acceleration facilitating greater muscle activation and force output [28]. The motor unit recruitment threshold is lower during a ballistic contraction than slow ramped contraction [13, 18, 45], which enables the entire motor neuron pool to be activated within a few milliseconds due to the strong excitatory drive of ballistic contraction [14]. BDJ includes two entirely different BE, a box jump, and a drop jump, which are categorized as slow and fast SSC, due to the duration of contraction time before the jump [36]. Slow-twitch and fast-twitch muscle fibers have different visco-elastic properties which allow them to benefit differently from both slow and fast SSC [6]. Tillin and Bishop [43] also proposed that greater neural excitation may be facilitated with drop jump due to its increased eccentric pre-loading components. MAT requires the use of both fast and slow SSC during multidirectional movements and changing directions. This combination of slow and fast SSC ballistic activity during BDJ could be a factor in the recruitment of different muscle fibers [6], thus potentiating both SSC qualities of muscle, and enhancing MAT performance. This improvement in the MAT performance may also be related to an acute increase of reactive strength [39] after the BDJ protocol. Reactive strength is the ability to change quickly from the eccentric phase to the concentric phase during an SSC muscle action [49]. Thus, a greater reactive strength would possibly improve the ability to perform sudden stops and to quickly accelerate from there [40], hence improving MAT performance. Also, BDJ protocol utilizes both fast and slow SSC abilities during the conditioning activity which might have helped to better utilize the SSC during the deceleration-acceleration transition of the COD movement.

Maloney et al. [24] suggested PAPE to be affected by the stiffness of the muscle-tendon unit. An increase in the stiffness at the musculotendinous unit level allows the muscle to function in a more quasi-isometric manner, increasing the potential for elastic recoil from the passive state which increases force development in the active component [31]. Thus, an increase in stiffness in the leg would improve reactive strength measures and relative force contribution of the SSC (i.e. passive tension to force production) during powerful movements due to the viscoelastic properties of the musculotendinous unit [1, 31]. Although we did not include stiffness measurement in the study, it is known that during ballistic activity, the muscle-tendon unit is required to stiffen to function effectively [31]. Plyometric training has also been effective in enhancing the extensibility of tendon during ballistic contractions and active muscle stiffness during fast stretching, improving performance during SSC activity [19].

Another finding of this study was insignificant changes in 15 m sprint performance, which is in line with previous studies [3, 8-10, 15, 21, 26, 42, 44, 46, 48]. These studies included plyometric as well as heavy resistance exercises as conditioning activity, such as double leg tuck jump, alternate leg bounding with or without weight, resisted sled sprints, power cleans, back squats with varied load and repetition. The sprint distance ranged from 5 m to 40 m and recovery duration from ~15 seconds to 16 minutes. In contrast, few studies also reported improvement in sprint performance using PAPE interventions [5, 7, 8, 22, 37, 44, 47]. The interventions included sled pulls with 75% and 150% of body mass, individualized drop jump, alternate leg bound using a weighted vest, drop jump with 0.75 m height, back squat, and power clean using varied load and repetition. The distance ranged from 15 m to 100 m, and recovery duration from 1 minute to 15 minutes. Due to these diverse findings of the previous studies, researchers suggest using individualized PAPE protocols for athletes. Figure 5 shows 25% of the subject did improve in 15 m sprints, which supports the previous observations that PAPE should be individualized when considering linear sprints.

An important concern to be noted in our study is an improvement in COD ability (MAT) but not in 15 m linear sprint performance, although MAT includes a total of 10 m linear sprints. Petisco et al. [32] had similar findings where they observed improvement in MAT performance but not in linear sprint performance. As per the authors' knowledge, the only study to incorporate a 15 m linear sprint test as a PAPE measure was by Winwood et al. [47] who used 15 m and 7.5 m sled pull with loads of 75% body mass and 150% body mass. Significant improvements were observed with 15 m sled pull with 75% body mass load and not in 7.5 m sled pull with 150% body mass. Winwood et al. [47] suggested providing adequate recovery of about 8 to 12 minutes for improving 15 m sprint performance. Our study provided a recovery duration of 3 minutes from the BDJ protocol to assessment which may not be adequate to induce PAPE in 15 m linear sprint. Another possible reason for this finding in our study may be due to fatigue while performing two trails of MAT before the 15 m sprint test. This may be addressed in future studies by conducting only linear sprint tests at different recovery interval following BDJ protocol.

This study has shown that combining slow and fast SSC ballistic activity provides an effective strategy for acutely improving MAT performance. Individualization of PAPE for COD ability may not be necessary for BDJ protocol with appropriate box height, as all the subjects in this study showed some improvement after BDJ (Figure 4), although individualization of box height or volume may be more beneficial and requires further studies. In contrast to this, our study also supports the previous findings that conditioning activity should be individualized when linear sprinting is a priority.

Conclusions

The results of this study suggest that BDJ protocol, specifically 3 sets of 5 repetitions is capable of inducing PAPE during MAT with a short 3 minutes recovery duration. Although boxes with varying height have been extensively used by many strength and conditioning coaches to perform box jumps or drop jumps separately, this is the first study to combine both the exercises into one and find possible benefits. Coaches may use box height of 0.65 m after specific warm-up to induce PAPE and gain maximal benefits. Also, the long-term effect of BDJ exercises on different performance measures can be further studied.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Arampatzis A, Schade F, Walsh M, Brüggemann GP. Influence of leg stiffness and its effect on myodynamic jumping performance. J Electromyogr Kinesiol. 2001;11(5):355-364. doi:10.1016/S1050-6411(01)00009-8.
2. Ben Abdelkrim N, El Fazaa S, El Ati J. Time motion analysis and physiological data of elite under-19 basketball players during competition. Br J Sports Med. 2007;41:69-75. doi:10.1136/bjsm.2006.032318.
3. Bevan HR, Cunningham DJ, Tooley EP, Owen NJ, Cook CJ, Kilduff LP. Influence of postactivation potentiation on sprinting performance in professional rugby players. J Strength Cond Res. 2010;24(3):701-705. doi:10.1519/JSC.0b013e3181c7b68a.
4. Bishop D. Warm up I: Potential mechanisms and the effects of passive warm up on exercise performance. Sports Med. 2003;33(6):439-454. doi:10.2165/00007256-200333060-00005.
5. Bomfim Lima J, Marin D, Barquilha G, Da Silva L, Puggina E, Pithon-Curi T, et al. Acute effects of drop jump potentiation protocol on sprint and countermovement vertical jump performance. Hum Mov. 2011;12(4):324--330. doi:10.2478/v10038-011-0036-4.
6. Bosco C, Tihanyi J, Komi PV, Fekete G, Apor P. Store and recoil of elastic energy in slow and fast types of human skeletal muscles. Acta Physiol Scand. 1982;116(4):343--349. doi:10.1111/j.1748-1716.1982.tb07152.x.
7. Byrne PJ, Kenny J, O'Rourke B. Acute potentiating effect of depth jumps on sprint performance. J Strength Cond Res. 2014;28(3):610-615. doi:10.1519/JSC.0b013e3182a0d8c1.
8. Chatzopoulos DE, Michailidis CJ, Giannakos AK, Alexiou KC, Patikas DA, Antonopoulos CB, et al. Postactivation potentiation effects after heavy resistance exercise on running speed. J Strength Cond Res. 2007;21(4):1278-1281. doi:10.1519/R-21276.1.
9. Comyns TM, Harrison AJ, Hennessy LK. Effect of squatting on sprinting performance and repeated exposure to complex training in male rugby players. J Strength Cond Res. 2010;24(3):610-618. doi:10.1519/JSC.0b013e3181c7c3fc.
10. Crewther BT, Kilduff LP, Cook CJ, Middleton MK, Bunce PJ, Yang GZ. The acute potentiating effects of back squats on athlete performance. J Strength Cond Res. 2011;25(12):3319-3325. doi:10.1519/JSC.0b013e318215f560.
11. Cronin JB, McNair PJ, Marshall RN. Is velocity-specific strength training important in improving functional performance? J Sports Med Phys Fitness. 2002;42(3):267-273.
12. Dello Iacono A, Martone D, Padulo J. Acute effects of drop-jump protocols on explosive performances of elite handball players. J Strength Cond Res. 2016;30(11):3122--3133. doi:10.1519/JSC.0000000000001393.
13. Desmedt JE, Godaux E. Ballistic contractions in man: characteristic recruitment pattern of single motor units of the tibialis anterior muscle. J Physiol. 1977;264(3):673--693. doi: 10.1113/jphysiol.1977.sp011689.
14. Duchateau J, Hainaut K. Mechanisms of Muscle and Motor Unit Adaptation to Explosive Power Training. In: Koomi PV, editor. Strength and Power in Sport. Blackwell Science Ltd; 2003. pp. 315-330.
15. Guggenheimer JD, Dickin DC, Reyes GF, Dolny DG. The effects of specific preconditioning activities on acute sprint performance. J Strength Cond Res. 2009;23(4):1135--1139. doi:10.1519/JSC.0b013e318191892e.
16. Hammami A, Zois J, Slimani M, Russel M, Bouhlel E. The efficacy and characteristics of warm-up and re-warm-up practices in soccer players: a systematic review. J Sports Med Phys Fitness. 2018;58(1-2):135-149. doi:10.23736/S0022-4707.16.06806-7.
17. Hodgson M, Docherty D, Robbins D. Post-activation potentiation: underlying physiology and implications for motor performance. Sports Med. 2005;35(7):585-595. doi:10.2165/00007256-200535070-00004.
18. Ivanova T, Garland SJ, Miller KJ. Motor unit recruitment and discharge behavior in movements and isometric contractions. Muscle Nerve. 1997;20(7):867-874. doi:10.1002/(SICI)1097-4598(199707)20:7<867::AID-MUS11>3.0.CO;2-P.
19. Kubo K, Ishigaki T, Ikebukuro T. Effects of plyometric and isometric training on muscle and tendon stiffness in vivo. Physiol Rep. 2017;5(15). doi:10.14814/phy2.13374.
20. Kümmel J, Bergmann J, Prieske O, Kramer A, Granacher U, Gruber M. Effects of conditioning hops on drop jump and sprint performance: a randomized crossover pilot study in elite athletes. BMC Sports Sci Med Rehabil. 2016;8(1). doi:10.1186/s13102-016-0027-z.

21. Lim JJ, Kong PW. Effects of isometric and dynamic postactivation potentiation protocols on maximal sprint performance. J Strength Cond Res. 2013;27(10):2730--2736. doi:10.1519/JSC.0b013e3182815995.
22. Linder EE, Prins JH, Murata NM, DeRenne C, Morgan CF, Solomon JR. Effects of preload 4 repetition maximum on 100-m sprint times in collegiate women. J Strength Cond Res. 2010;24(5):1184-1190. doi:10.1519/JSC.0b013e3181d75806.
23. Lum D, Chen SE. Comparison of loaded countermovement jump with different variable resistance intensities on inducing post-activation potentiation. J Sci Sport Exerc. 2020;2:167-172. doi:10.1007/s42978-020-00055-4.
24. Maloney SJ, Turner AN, Fletcher IM. Ballistic exercise as a pre-activation stimulus: a review of the literature and practical applications. Sports Med. 2014;44(10):1347--1359. doi:10.1007/s40279-014-0214-6.
25. Maloney SJ, Turner AN, Miller S. Acute effects of a loaded warm-up protocol on change of direction speed in professional badminton players. J Appl Biomech. 2014;30(5):637-642. doi:10.1123/jab.2014-0048.
26. McBride JM, Nimphius S, Erickson TM. The acute effects of heavy-load squats and loaded countermovement jumps on sprint performance. J Strength Cond Res. 2005;19(4):893-897. doi:10.1519/R-16304.1.
27. McGowan CJ, Pyne DB, Thompson KG, Rattray B. Warm-up strategies for sport and exercise: mechanisms and applications. Sports Med. 2015;45(11):1523-1546. doi:10.1007/s40279-015-0376-x.
28. Newton RU, Kraemer WJ, Hakkinen K, Humphries BJ, Murphy AJ. Kinematics, kinetics, and muscle activation during explosive upper body movements. J Appl Biomech. 1996;12(1):31-43.
29. Ng CY, Chen SE, Lum D. Inducing postactivation potentiation with different modes of exercise. Strength Cond J. 2020;42(2):63-81. doi:10.1519/SSC.0000000000000522.
30. Okuno NM, Tricoli V, Silva SB, Bertuzzi R, Moreira A, Kiss M. Postactivation potentiation on repeated-sprint ability in elite handball players. J Strength Cond Res. 2013;27(3):662-668. doi:10.1519/JSC.0b013e31825bb582.
31. Pearson SJ, McMahon J. Lower limb mechanical properties: determining factors and implications for performance. Sports Med. 2012;42(11):929-940. doi:10.1007/bf03262304.
32. Petisco C, Ramirez-Campillo R, Hernández D, Gonzalo-Skok O, Nakamura FY, Sanchez-Sanchez J. Post-activation potentiation: effects of different conditioning intensities on measures of physical fitness in male young professional soccer players. Front Psychol. 2019;10. doi:10.3389/fpsyg.2019.01167.
33. Potach DH, Chu DA. Plyometric Training. In: Baechle TR, editor. Essentials of Strength Training and Conditioning. Human Kinetics; 2008. pp. 413-456.
34. Prieski O, Behrens M, Chaabene H, Granacher U, Maffiuletti NA. Time to differentiate postactivation „potentiation" from „performance enhnacement" in strength and conditioning community. Sports Med. 2020. doi:10.1007/s40279-020-01300-0.
35. Sassi RH, Dardouri W, Yahmed MH, Gmada N, Mahfoudhi ME, Gharbi Z. Relative and absolute reliability of a modified agility t-test and its relationship with vertical jump and straight sprint. J Strength Cond Res. 2009;23(6):1644-1651. doi:10.1519/JSC.0b013e3181b425d2.
36. Schmidtbleicher D. Training for Power Events. In: Komi PV, editor. The Encyclopedia Of Sports Medicine. Vol. 3. UK: Blackwell: Oxford; 1992. pp. 169-179.
37. Seitz LB, Trajano GS, Haff GG. The back squat and the power clean: elicitation of different degrees of potentiation. Int J Sports Physiol Perform. 2014;9(4):643--649. doi:10.1123/ijspp.2013-0358.
38. Sheppard J, Young W. Agility literature review: classifications, training and testing. J Sports Sci. 2006;24(9):919-932. doi:10.1080/02640410500457109.
39. Sole CJ, Moir GL, Davis SE, Witmer CA. Mechanical analysis of the acute effects of heavy resistance exercise warn up on agility performance in court sport athletes. J Hum Kinet. 2013;39(1):147156. doi:10.2478/hukin-2013-0077.
40. Spiteri T, Cochrane JL, Hart NH, Haff GG, Nimphius S. Effect of strength on plant foot kinetics and kinematics during a change of direction task. Eur J Sport Sci. 2013;13(6):646-652. doi:10.1080/17461391.2013.774053.
41. Thapa RK, Kumar A, Sharma D. Effect of drop height on different parameters of drop jump among soccer players. Trends Sport Sci. 2020;27(1):13-18. doi:10.23829/TSS.2020.27.1-2.
42. Till KA, Cooke C. The effects of postactivation potentiation on sprint and jump performance of male academy soccer players. J Strength Cond Res. 2009;23(7):1960-1967. doi:10.1519/JSC.0b013e3181b8666e.
43. Tillin NA, Bishop D. Factors modulating post-activation potentiation and its effect on performance of subsequent explosive activities. Sports Med. 2009;39(2):147-166. doi:10.2165/00007256-200939020-00004.
44. Turner AP, Bellhouse S, Kilduff LP, Russell M. Postactivation potentiation of sprint acceleration performance using plyometric exercise. J Strength Cond Res. 2015;29:343-350. doi:10.1519/JSC.0000000000000647.
45. Van Cutsem M, Duchateau J, Hainaut K. Changes in single motor unit behaviour contribute to the increase

in contraction speed after dynamic training in humans. J Physiol. 1998;513(1):295-305. doi:10.1111/j.1469-7793.1998.295by.x.

46. Whelan N, O'Regan C, Harrison AJ. Resisted sprints do not acutely enhance sprinting performance. J Strength Cond Res. 2014;28(7):1858-1866. doi:10.1519/JSC.0000000000000357.
47. Winwood PW, Posthumus LR, Cronin JB, Keogh JWL. The acute potentiating effects of heavy sled pulls on sprint performance. J Strength Cond Res. 2016;30(5):1248--1254. doi:10.1519/JSC.0000000000001227.
48. Wyland TP, van Dorin JD, Reyes GFC. Postactivation potentiation effects from accommodating resistance combined with heavy back squats on short sprint performance. J Strength Cond Res. 2015;29(11):3115--3123. doi:10.1519/JSC.0000000000000991.
49. Young WB, Jenner A, Griffiths K. Acute enhancement of power performance from heavy load squats. J Strength Cond Res. 1998;12(2):82-94.