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POST-ACTIVATION PERFORMANCE ENHANCEMENT EFFECT OF TWO TUCK-JUMP PROTOCOLS WITH DIFFERENT VOLUMES ON 15-S VERTICAL JUMP PERFORMANCE

UČINEK METODE PAPE PRI DVEH PROTOKOLIH VERTIKALNIH POSKOKOV NA PARAMETRE ZMOGLJIVOSTI PRI PONAVLJAJOČIH VERTIKALNIH SKOKIH

ABSTRACT

Post-activation performance enhancement is a principle that suggests that an acute bout of high intensity voluntary exercise will be followed by an improvement in strength, power, jump and speed of a subsequent task. This study aimed to investigate changes in 15 s repetitive vertical jump performance after one set (1 x 10 repetitions) or three sets (3 x 10 repetitions) of tuck jumps conditioning activity. Twelve male (age 21.6 ± 1.5 years) trained volleyball players participated in this study. The participants performed three experimental sessions with a randomized, counterbalanced, and crossover research design: a-) single set of tuck jump (SJ); b-) multiset of tuck jump (MJ); and c-) control (CON). Each experimental session was composed of a standard warm-up, conditioning activity, 5 minutes of rest, and then 15 s vertical jump test, respectively. Peak (p=0.029) and average (p=0.018) jump height, peak (p=0.029) and average (p = 0.007) power output were significantly greater in SJ than CON. No significant differences were observed in the fatigue index between conditions (p=0.657). Overall, there were no significant differences in any parameters between MJ and CON and between SJ and MJ (p>0.05). These results showed that a SJ could improve repetitive vertical jump performance in trained male volleyball players, but caution should be given while using MJ before trainings or matches including activities with repetitive jumping.

Keywords: countermovement jump; PAPE; post-activation potentiation; plyometric conditioning; volleyball

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IZVLEČEK

Povečanje zmogljivosti po aktivaciji je načelo, ki predpostavlja, da bo po akutni seriji visoko intenzivne dejavnosti sledilo izboljšanje jakosti, moči, skoka in hitrosti pri naslednji nalogi. Namen te študije je bil raziskati spremembe v zmogljivosti ponavljajočih se navpičnih skokov v 15 sekundah po eni seriji (1 x 10 ponovitev) ali treh serijah (3 x 10 ponovitev) skokov s pritegom kolen k prsim. V raziskavi je sodelovalo dvanajst treniranih odbojkarjev (starih 21,6 ± 1,5 let). Udeleženci so izvedli tri eksperimentalne treninge z naključnim, uravnoteženim in križnim raziskovalnim načrtom: a-) ena serija skokov s pritegom kolen k prsim (SJ); b-) več serij skokov s pritegom kolen k prsim (MJ); in c-) kontrolna skupina (CON). Vsak eksperimentalni trening je vključeval standardno ogrevanje, specifično ogrevanje, 5 minut počitka in nato 15-sekundni test navpičnih poskokov. Najvišja (p=0,029) in povprečna (p=0,018) višina skoka, najvišja (p=0,029) in povprečna (p = 0,007) moč sta bili v eksperimentalni skupini statistično značilno večji kot v kontrolni skupini. Med različnimi pogoji ni bilo ugotovljenih pomembnih razlik v indeksu utrujenosti (p=0,657). Na splošno ni bilo najdenih pomembnih razlik v nobenem parametru med skupino, ki je izvajala več serij poskokov in kontrolno skupino ali med MJ in CON ter med SJ in MJ (p>0,05). Ti rezultati so pokazali, da lahko SJ izboljša zmogljivost ponavljajočih se navpičnih skokov pri treniranih moških odbojkarjih, vendar je treba biti previden pri uporabi MJ pred treningi ali tekmami, ki vključujejo dejavnosti s ponavljajočimi se skoki.

Ključne besede: skok z nasprotnim gibanjem, PAPE, povečanje zmogljivosti po aktivaciji, pliometrični trening, odbojka

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INTRODUCTION

The improvement of electrically evoked twitch force refers to the traditional term "post-activation potentiation" (PAP) (Robins, 2005), while more recently, the term "post-activation performance enhancement" (PAPE) has been used to specify the increase in force and power output because of voluntary contractions (Cuenca-Fernández et al., 2017). These terms describe different structures and have been used interchangeably. Although PAPE's exact mechanism is not fully understood, there is evidence linking PAPE to an increase in intramuscular water content and muscle temperature as well as an elevation in alpha motor neuron excitability and phosphorylation of myosin regulatory light chains, which makes them more responsive to myoplasmic Ca2+ and acute alterations in muscle architecture such as a decrease in the pennation angle (Blazevich & Babault, 2019). It usually occurs in a 4-10 min time window after an application of a relatively high-intensity strength or speed-based exercise that is named the conditioning activity (CA) (Sale, 2002). These concepts of PAP and PAPE, and their practical applications, have gained widespread attention in the field of sport science due to their potential for optimizing athletic performance. Athletes and coaches across a diverse range of sports often incorporate these techniques into their training regimens, exploiting the short-term enhancement in muscle force, speed and jump that these methods can deliver.

Plyometric exercises have been scientifically demonstrated to increase muscle force and speed (Chu & Meyer, 2013). Fundamentally, plyometrics exploit the stretch-shortening cycle (SSC), a natural mechanism that involves the rapid transfer of force through storage and release by the body's passive structures, particularly the series elastic component (SEC) such as tendons (Komi, 2000). During the eccentric phase of a movement, these elastic components store potential energy. This energy is swiftly released as the movement transitions to the concentric phase, increasing the force and speed of muscle contractions (Cormie, McGuigan & Newton, 2011). Consequently, plyometric exercises offer a method for the targeted development of the neuromuscular system's capacity to generate force quickly and efficiently. Implementing those types of exercises as a CA in PAPE applications is one of the greatest alternatives to traditional resistance type CAs (Till & Cooke, 2009; Seitz & Haff, 2016; Turner, Bellhouse, Kilduff & Russell, 2015; Tillin & Bishop, 2009; Esformes, Cameron & Bampouras, 2010). According to Turner et al., using plyometric exercise is a beneficial technique to enhance sprint performance by inducing the PAPE (Turner, Bellhouse, Kilduff & Russell, 2015). Applications of PAPE can increase the rate of force development (Sale, 2002; Tillin & Bishop, 2009), which is essential in sports requiring high-speed outputs. A rich body of literature underlines the importance of plyometric CA in this context, with numerous studies exploring its impact on PAPE (Maloney, Turner & Fletcher, 2014). Masamoto et al. (2003), investigated the effects of three double-leg tuck jumps and two depth jumps on subsequent 1RM squat performance, and observed an improvement in 1RM squat performance by 4,9 kg (3.5%) only after two depth jumps. McBride et al. conducted a single set of 3 repetitions of a loaded countermovement jump (CMJ) at 30% of 1RM but found no differences in 40-m sprint performance after 4 minutes of rest. In that study, authors have attributed the lack of any performance outcomes to the inadequacy of the single set for inducing PAPE. Additionally, Till & Cooke and Tsolakis et al. reported that tuck jump protocols had no effect on performance. Since these studies (Masamoto, Larson, Gates & Faigenbaum, 2003; McBride, Nimphius & Erickson, 2005; Till & Cooke, 2009; Tsolakis, Bogdanis, Nikolaou & Zacharogiannis, 2011) reported conflicting findings, further investigation is required to determine whether plyometric exercises could potentially cause PAPE. The acute response to a heavy resistance stimulus has been thoroughly researched (Tsolakis, Bogdanis, Nikolaou & Zacharogiannis, 2011; Crewther et al., 2011; Suchomel, Sato, DeWeese, Ebben & Stone, 2016), and an increasing amount of evidence indicates the possibility that plyometric ballistic exercises could also serve as an alternative PAPE method (Till & Cooke, 2009; Maloney, Turner & Fletcher, 2014). The investigation and comprehension of these mechanisms continue to be a focus of sport and exercise science research, contributing to our growing understanding of optimal performance conditioning and recovery strategies.

Utilizing PAPE prior to competition would indeed be simpler if it were done without the requirement for expensive and heavy equipment (Maloney, Turner & Fletcher, 2014). Furthermore, PAPE via plyometric exercises can be more time efficient compared to a heavy resistance stimulus because this potentiation might occur with reduced acute fatigue, allowing for more time-efficient, and hence shorter, rest periods between sets of plyometric exercises. Plyometric exercises could be a good substitute for heavy resistance type CA for PAPE if properly implemented. The number of sets, rest interval, and CA type are all significant elements for improving the performance output. Whilst fatigue develops following a CA, potentiation occurs, and the ratio of these two processes is what determines the final performance enhancement magnitude (Tillin & Bishop, 2009). Furthermore, previous research on PAPE via plyometric exercises has examined one-time performance (single vertical jump) results. (Tobin & Delahunt, 2014; Sharma et al., 2018; Krzysztofik, Kalinowski, Filip-Stachnik, Wilk & Zajac, 2021). Tobin and Delahunt (2014), reported that one-time CMJ performance improved at 1, 3 and 5 minutes after plyometric CA (total 40 jumps). Sharma et al. (2018), demonstrated that one-time CMJ performance increased at the 10th minute after plyometric CA involving 40 jumps. Krzysztofik et al. (2021), also performed a one-time attack jump and standing spike attack performance on volleyball players with a self-selected rest intervals after plyometric CA (total of 15 jumps). As a result, researchers found no acute performance improvement. However, especially in team sports such as volleyball, handball and basketball, repeated jumps take place instead of a single jump (Okuno et al., 2013; Peña, Moreno-Doutres, Coma, Cook & Buscà, 2018). Thus, single-time performances do not fully reflect the repetitive, intermittent, and high-intensity nature of team sports. 15 seconds of continuous CMJs may not directly replicate the intermittent jumping patterns typically observed in these sports, where jumps are followed by limited recovery periods. However, our selection of the continuous 15-s CMJ test was based on the desire to investigate maximum jump performance over a short period of time, which is a crucial aspect of performance in a variety of sports such as volleyball, handball, and basketball. Continuous jumping tests have been widely used in the literature as they are excellent for assessing maximum jump performance over a short period of time (Del Coso et al., 2012; Nikolaidis, Ingebrigtsen, Póvoas, Moss & Torres-Luque, 2016) and it can be proposed that they still hold value as an indirect measure of an athlete's potential performance in sports. While we acknowledge the deviation from exact game conditions, we argue that this method presents a novel approach to exploring performance enhancement mechanisms. This could inspire future research which more closely aligns with the activity patterns of team sports such as volleyball, handball, and basketball., thus bridging the gap between laboratory findings and field application. Therefore, the aim of this study was to investigate the effects of applying a single set or multiple sets of plyometric exercises on 15-s vertical jump performance. It was hypothesized that PAPE effect would be observed after single and multiple tuck jump conditioning activities.

METHODS

Study Design

A randomized, counterbalanced, repeated-measures design was used to compare the PAPE effects caused by single or multi set plyometric activities throughout three trials and to identify any possible differences between the 3 conditioning stimuli. Which protocol participants would follow on which day was determined by a simple randomization method using a random number table. On each test day, participants were divided into equal numbers and randomly assigned to different protocols (4 participants CON, 4 participants SJ, 4 participants MJ). The first laboratory visit was used for familiarization and to perform anthropometric measurements. In the subsequent three trials, the participants performed 15-second vertical jump tests. Each session consisted of 15 s vertical jump test preceded by a CA. The conditioning stimulis were (1) a single set of jump (SJ) (1 x 10 rep.), (2) multi set of jump (MJ) (3 x 10 rep.), or (3) control (CON). Each participant completed a standardized warm-up and PAPE protocols before each trial. Following the warm-up and PAPE protocol, participants rested in seated position (passive rest) for 5 min and subsequently performed a 15 s vertical jump test (Bosco, Luhtanen & Komi, 1983). Throughout the trials, participants drank water ad libitum, and same two member of the study team conducted all tests to reduce any variance in test instruction. At the beginning of each visit, participants were made aware of the condition to which they would be exposed. All the test sessions were separated by 72 h to allow recovery. All experiments were carried out in the same laboratory, where the temperature was fixed and kept between 21 ± 2 °C at the same time of day (3:00 p.m./4:00 p.m.) to control the effects of the circadian rhythm. In addition, participants were instructed to refrain from eating two to three hours before each testing session. All participants were asked to wear appropriate running shoes and had the same training gear (t-shirt, shorts, and socks) to reduce the potential for variation in the test design.

Participants

The number of required participants was determined with the G*Power software (3.1.9.7 version, University Dusseldorf, Germany). For the analysis, the following parameters were assumed: an effect size (ES) of 0.20 for a vertical jump; an alpha level of 0.05; overall effect size 0.85; r of 0.90; 1 group and 3 measures (Krzysztofik, Kalinowski, Filip-Stachnik, Wilk & Zajac, 2021). The power analysis revealed that this investigation needed a sample size of 11 individuals. To accommodate for any potential dropouts, we enrolled 12 trained males. Twelve male trained (McKay et al., 2022) volleyball players (Table 1) voluntarily participated in this study. The inclusion criteria were individuals with at least 5 years of training experience and actively playing volleyball. As exclusion criteria, participants who had any chronic disease or lower extremity injury in the last year or who needed to take medication continuously were not included in the study. All athletes had 7.5 ± 2.5 years of competitive club volleyball experience and had played in regional and university-level leagues. Participants had participated in volleyball training for at least 4 × 2 hours per week over the past two years. All participants were instructed to adhere to their regular diet and refrain from taking any dietary ergogenic aids or stimulants during the experiment. Before giving "written informed consent" to voluntarily participate in the study, participants were informed about the study aims, methods and associated risks. All participants were advised not to engage in vigorous physical activity and not to consume alcohol and caffeine for 24 hours prior to the measurements. This experimental protocol was approved by the Mus Alparslan University Scientific Research Ethics Committee (Approval no: 73181-12/40). The study was conducted according to the principles of the Declaration of Helsinki (1983).

Table 1. Participants' characteristics.

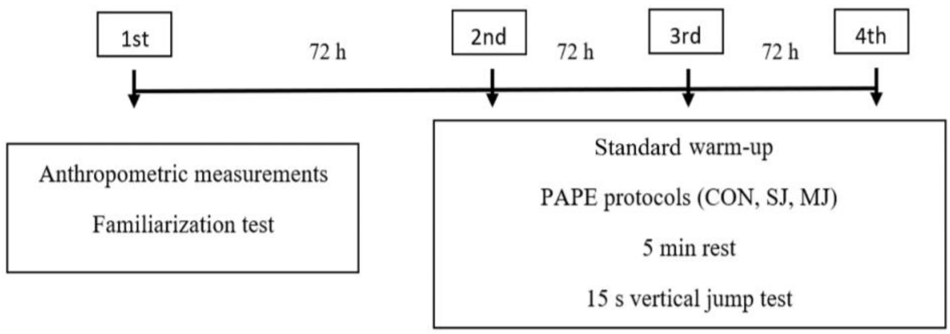
Characteristics	**Mean + SD**
Age (years)	21.6 ± 1.5
Body weight (kg)	70.0 ± 4.9
Body height (cm)	180.6 ± 4.7
Body mass index (kg/m^2)	21.6 ± 2.6
Body fat (%)	7.7 ± 1.8
Volleyball experience (years)	7.5 ± 2.5

Procedures

The participants attended a familiarization session one week prior to the start of the study to become familiar with the protocols and testing procedures. On the same day, anthropometric height, with a 1 mm stadiometer (Seca 213, Hamburg, Germany), and body mass measurements (Tanita Body Composition Analyzer MC-780MA, Tokyo, Japan) were obtained. 15 second vertical jump test was used to assess the participants' jump height, and, for the first time in the literature, fatigue index which is relevant to team sports where quality in consistency of repetitive jumping can be an advantage in gaining an edge over the opponent. Upon each visit, participants first warmed up by running on a treadmill at a constant speed of 6,5 km/h for 5 minutes. Then, they performed dynamic stretches for 2 minutes. The dynamic exercises, each consisting of 10 repetitions, included the following movements: Knee to chest calf raises; heel to hip calf raises; external rotation with calf raises to the hip; hamstring stretch half step forward. Participants were warned not to do static stretching, jumping, and short sprint runs during dynamic stretching period. After an active recovery with 2 min by walking, PAPE protocols were performed. Following a 5 min passive rest, 15 second vertical jump test was then conducted. The design for this experimental process is illustrated in Figure 1.

Figure 1. Experimental design. CON = control, SJ = single set jump, MJ = multi set jump.

PAPE Protocols



In the SJ protocol, participants performed 10 repetitions of tuck jumps. In the MJ protocol, 3 x 10 repetitions of tuck jumps were performed, separated by 30 s rest. No preload was applied in the CON protocol. During CON protocol, participants walked continuously for 2 minutes at a modest speed (5 km/h) in order to limit temperature loss compared to the PAPE condition. Tuck jumps were performed as a fast stretch-shortening cycle action. The tuck jumps in SJ and MJ protocols started with a countermovement, which was followed by a maximum vertical jump while simultaneously bringing the knees toward the chest. Participants were verbally encouraged to attain maximum vertical displacement and minimize ground contact duration throughout each repetition (Read, Oliver, Mark, Myer & Lloyd, 2016).

15-Second Vertical Jump Test

The 15-s vertical jump tests were performed on a mobile contact mat (Smart Jump; Fusion Sport, Queensland, Australia) (Reeve & Tyler, 2013). Following a voice signal, the participants began the test in an upright position with weights evenly distributed on both feet and arms positioned at the waist. For each jump, participants squatted until their knees were bent about 90°, jumped vertically as high as possible, and landed with both feet simultaneously, repeating the jump for 15 seconds. Participants were asked to remain with their trunk in the vertical positioning with no excessive forward move, having their knees extended during the flight phase, and jump as many times and as high as possible for 15 seconds. The repeated 15-seconds jumping test procedure had as basis the description made by Bosco et al. (1983), whose reliability for the continuous 15-seconds vertical jumping test has been reported as high, r = 0.95. Jump height, power and fatigue index (FI) were recorded. The fatigue index was obtained considering the first (HMEAN_4J) and the last (HMEAN_end4J) four jumps of the test (Maud & Foster, 2009), according to Eq:

$$\text{Fatigue Index} = [(\text{HMEAN\_4J} - \text{HMEAN\_end4J}) / \text{HMEAN\_4J}] \times 100$$

Statistical Analyses

IBM SPSS 22.0 (IBM Corp., Armonk, New York, USA) was used in the analysis of the data. A Shapiro–Wilk test was used to confirm normal distribution. The 15 s vertical jump performances were evaluated using one-way repeated measures ANOVA. Mauchly's test analyzed the sphericity assumption followed by the Greenhouse–Geisser adjustment if required. If significant interactions or main effects were detected, pairwise comparisons with Bonferroni's corrections were applied. For each paired comparison, Cohen's d effect sizes were calculated, which range from trivial (d <0.20); small (d between 0.20 and 0.49); moderate (d between 0.50 and 0.79) and large (d ≥ 0.80) (Cohen, 1992). To assess the test–retest consistency of the three test sessions, intraclass correlation coefficients (ICC) were obtained and interpreted as follows: poor reliability: <0.5, moderate reliability: 0.5-0.75, good reliability: 0.75-0.90, and excellent reliability:>0.90 (Portney & Watkins, 2008).

RESULTS

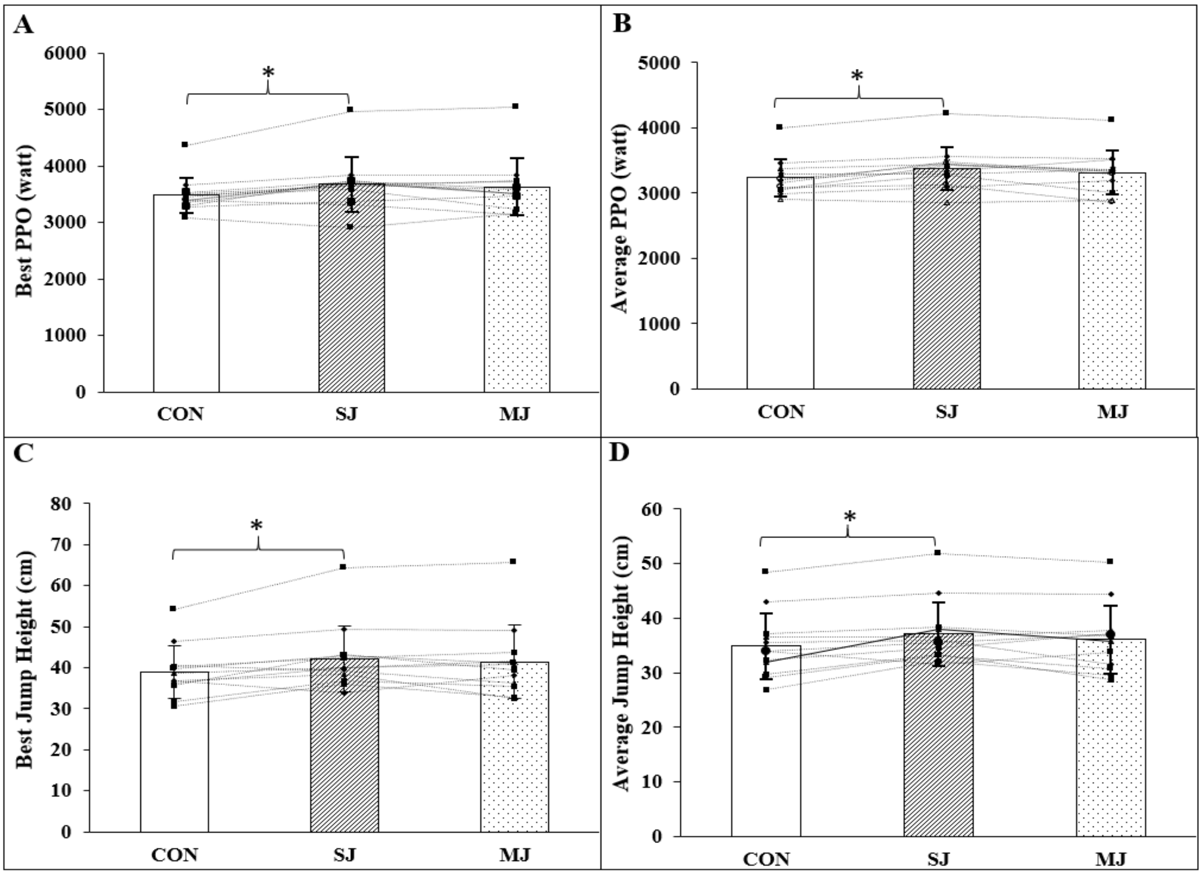
Table 2 shows the peak and average jump height, power output and fatigue index (%). There was a statistically significant difference between the PAPE protocols in the peak jump height (F = 5.464; p = 0.012), average jump height (F = 5.554; p = 0.011), the peak power output (F = 5,452; p = 0,012) and average power output (F = 6,695; p = 0,005). The Bonferroni post hoc test showed that single set of tuck jump protocol improved performance compared to control in the peak jump height (p = 0.029; d = 0.44), average jump height (p = 0.018; d = 0.38), the peak power output (p = 0,029; d = 0,48), and average power output (p = 0,007; d = 0,46) (Figure 2). There was no significant difference in fatigue index (F = 0.428; p = 0.657) (Table 2). ICC values are 0.96 for peak jump height, 0.97 for average jump height, 0.95 for peak power output and 0.96 for average power output which means 15 seconds vertical jump test performed with excellent reliability.

Table 2. 15 s vertical jump parameters after PAPE protocols (n = 12).

	CON	SJ	MJ
Parameters		**Mean ± SD (Δ (%))**	
The peak jump height (cm)	38.93 ± 6.31	42.16 ± 8.05*	41.37 ± 8.93
Δ (%)	-	+ 8.2	+ 6.2
Average jump height (cm)	34.88 ± 5.99	37.15 ± 5.82*	36.12 ± 6.21
Δ (%)	-	+ 6.5	+ 3.5
The peak PO (W)	3479.61 ± 313.02	3675.58 ± 483.50*	3627.61 ± 500.82
Δ (%)	-	+ 5.6	+ 4.2
Average PO (W)	3233.91 ± 89.10	3379.19 ± 330.31*	3313.52 ± 337.33
Δ (%)	-	+ 4.4	+ 2.4
FI (%)	13.28 ± 8.54	12.26 ± 8.41	12.91 ± 7.03
Δ (%)	-	- 7.6	- 2.7

CON = control; SJ = single set jump; MJ = multi set jump; PO= power output; FI = fatigue index; SD = standard deviation; Δ (%): percentage change according to CON. *: p<0,05 compared to CON.

Figure 2. 15 s vertical jump parameters after PAPE protocols; PO: power output, CON: control, SJ: single set jump, MJ: multi set jump; *: SJ was significantly different than CON.



DISCUSSION

The aim of this study was to compare the impact of performing one set (1x10) versus three sets (3x10) of plyometric CA on 15 s CMJ performance. Our results demonstrated that after solely one set of plyometric CA, both peak and average jump height, peak and average power output were considerably higher than in the control trial. Multi-set plyometric CA did not improve 15 s CMJ performance. The fatigue index also did not differ significantly between trials. Further, no differences were observed between one and three sets of plyometric CA.

To our knowledge, this is the first study to use plyometric CAs with different repetition numbers and repeated CMJ testing to assess the effect of PAPE. Jumping occurs multiple times rather than just once in team sports like volleyball, basketball and handball (Okuno et al., 2013; Peña, Moreno-Doutres, Coma, Cook & Buscà, 2018). As such, employing the repeated jump test for the PAPE effect is appropriate. PAPE may be more easily detectable because the 15-second vertical jump test requires multiple trials rather than a single jump. Although 15 s repetitive jump per-formance has not been investigated in prior PAPE investigations, the findings of this study are consistent with earlier research indicating that low-volume plyometric CAs can increase vertical jump performance (Chen, Wang, Peng, Yu & Wang, 2013; Dallas, Dallas & Tsolakis, 2019; Baena-Raya, Sánchez-López, Rodríguez-Pérez & Garcia-Ramos, 2020; Krzysztofik et al., 2022). Chen et al. (2013), tested male volleyball players using drop jump CA with one or two sets of 5 repetitions (1 min rest between sets) and reported that CMJ enhanced after applying CA in both treatments. In another study (Dallas, Dallas & Tsolakis, 2019) 2 x 5 repetitions tuck jumps improved drop jump performance in the 6th and 9th minutes. Further, the effects of various volumes of drop jump CA on the CMJ were examined by Baena-Raya et al. (2020), in which it was shown that both a single set of 5 repetitions and 3 x 5 repetitions of drop jump improved CMJ height at 4, 8, and 12 minutes, although the low volume CA (5 drop jump) had a greater effect. Lastly, Krzysztofik et al. (2022), showed an increase in jump height in the 9th minute after applying 3 x 5 tuck jumps CA in amateur male soccer players. Based on these and our findings, a low (5-15 repetitions) volume of plyometric CAs appears to be an effective stimulus for a 15 s or single vertical jump performance enhancement. The meta-analysis by Seitz and Haff, highlighted that the time required for the greatest PAPE effect may be affected by the type of CA. Specifically, the greatest PAPE effect has been reported to occur 0, 3–4 minutes after a plyometric CA, while it takes at least 5 minutes for con-ventional high- and moderate-intensity resistance exercises (Seitz & Haff, 2016). It has been suggested that a high level of individualization is needed in complex and equipment-required

CA designs such as heavy resistance exercises (Comyns, Harrison, Hennessy & Jensen, 2006; Weber, Brown, Coburn & Zinder, 2008; Bevan et al., 2010; Nibali, Mitchell, Chapman & Drinkwater, 2011). Therefore, such CA designs may not be practical in team sports. Eleven out of twelve participants in the present study pro-duced a positive response to a single set of plyometric CA, resulting in a significant enhancement in 15 s repetitive vertical jump performance. Our finding offers the applica-tion of a single set of plyometric CA as a practical and appropriate method for practi-tioners when attempting to exploit the PAPE phenomenon.

Multi-set CA did not increase 15 s vertical jump performance in our study. This multiple-set CA may have caused fatigue and thus blunted the potential of PAPE. However, percentage increases were observed in all vertical jump parameters in mul-ti-set CA compared to control trial (~4%) and these percentage increases were very close to the single set CA (Table 2). There was also no statistically significant difference between the sessions, based on the FI findings. Consistently, Esformes et al. (2010), reported that CMJ performance did not differ following a series of plyometric exercises (1 set 6 repeat, alternate speed bounds, right leg speed hops, left leg speed hops, and vertical bounds, 15 s rest interval, total 24 jumps). Authors have attributed this lack of effect to the potential metabolic fatigue that likely occurred due to the fact that the duration of the plyometric exercises (~70 seconds) was too long. Interestingly, Till and Cooke (2009), reported that five-tuck jumps had no meaningful effect on CMJ performance. This may be because the volume of the stimulus was too low to generate a PAPE response for participants. Collectively, these findings indicate the importance of the volume of plyometric CA as it might cause either potentiation or fatigue (Hanson, Leigh & Mynark, 2007; Khamoui et al., 2009). It is also important to highlight that whether CA volumes elicit PAPE or fatigue depends on the individual's strength level. From the present literature, it is not yet clear to determine how the individual’s strength level dictates the PAPE response following plyometric CAs. Therefore, future research that addresses this uncertainty is needed. Further-more, while volume appears to be a factor influencing PAPE responses, it should be evaluated with the intensity and/or type of plyometric CA (Seitz & Haff, 2016). Each type of plyometric CAs may induce different PAPE mechanisms of actions, in turn, overall various out-comes (Brink, Constantinou & Torres, 2023). In this regard, further research is required to investigate PAPE effects of various forms of plyometric CA (tuck, drop etc.) on vertical jump performance.

There are several other factors that can influence the effect of PAPE. Studies have indicated that recovery times following CA may impact the PAPE response, and that these optimal rest intervals may also depend on the strength level of individuals (Hamada, Sale, Macdougall &

Tarnopolsky, 2000; Chiu & Barnes, 2003; Seitz & Haff, 2016; Blazevich & Babault, 2019). It is likely that why the multi-set CA (3 x 10 reps) in this research was unable to improve jump performance was attributable to the short recovery time after CA. There is evidence to suggest that the longer the rest period, the greater the effect of plyometric CA on the vertical jump performance (Sharma et al., 2018). However, the literature is still too limited and therefore further research is required to assess and determine the optimal resting time following plyometric CA. Moreover, team sports, in particular, require repeated rapid actions as opposed to a single intense activity. The majority of past PAPE research has focused solely on single-performance outcomes (Tobin & Delahhunt, 2014; Krzysztofik, Kalinowski, Filip-Stachnik, Wilk & Zajac, 2021; Sari, Koz, Salcman, Gabrys & Karayigit, 2022). One-off performances do not adequately reflect the repetitive, intermittent, and high-intensity nature of team sports. As such, evaluating PAPE's effect on repetitive jumps, sprints, changes of direction, or test batteries specific to sports branches can be more realistic when it comes to investigating its effects on real-game performance in terms of its applicability.

The present study has various limitations that should be addressed when interpreting the findings. Although the single set of tuck jump protocol enhanced 15-s repetitive vertical jump performance, exact mechanisms cannot be explained. Future studies should include the measurement of skin surface temperature or viscoelastic muscle properties during investigating plyometric conditioning activities on vertical jumping performance. Furthermore, our participants were regional and university level volleyball players. Therefore, the results may not directly transfer to elite level athletes. It should not be ignored that in our trial, a single 5-minute rest interval was provided. Different rest intervals (10 or 15 minutes) may need to be examined, as par-ticipants' strength levels and responses to CA may differ. While CA for PAPE is associated with enhanced performance, it should be kept in mind that other physically, physiological and psychological factors may play a role in determining performance. Due to the potential for individual characteristics of participants such as height, body mass, BMI, and personal training programs to influence vertical jump performance, in-dividual characteristics should be considered when evaluating plyometric CAs and subsequent vertical jump performance. More research is needed to determine whether the plyometric CAs applied in this study will affect more specific and technical movement patterns applied during training or competition.

CONCLUSION

Low volume single set of plyometric CA (1x10 tuck jump) with a 5-minute rest time improved 15 s repeated jump performance in trained male volleyball players, while multi-set plyometric CA did not provide a significant effect. On the other hand, it should be kept in the mind that multi-set of plyometric CA enhanced jump performance ~4% averagely (Table 2). Lastly, 11 out of 12 participants responded positively to both single and multi-set of plyometric CA. In team sports involving repetitive rapid actions, plyometric CAs, which do not require any equipment before training or competition and do not take a long time, seem to be a very practical and beneficial method for practitioners and athletes. PAPE methods should take into account participants' training status as well as individual differences.

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Declaration of Conflicting Interests

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