ORIGINAL ARTICLE

TRENDS in
Sport Sciences
2021; 28(**4**): 273-280
ISSN 2299-9590
DOI: 10.23829/TSS.2021.28.4-4

Does different repetition duration modify the post-activation performance enhancement effects?

WESLEY MARÇAL SANTOS[1,2], OTÁVIO RODRIGUES COSTA[2], BRUNO PEREIRA MELO[3],
MILLER PEREIRA GUIMARÃES[2,4], YURI DE ALMEIDA COSTA CAMPOS[2,5],
SANDRO FERNANDES DA SILVA[2,6]

Abstract

Introduction. **The post-activation performance enhancement (PAPE) is a phenomenon characterized by an acute enhancement of maximal voluntary strength, power or speed and have been used to increase acute performance in explosive activities. However, the effects of different repetition duration during the conditioning activities in PAPE have not been established yet.** Aim of Study. **The present study aimed to compare two different repetition duration a) Conditioning Activity Concentric (CAConc) (i.e., 1-sec-eccentric/3-sec-concentric), and b) Conditioning Activity Eccentric (CAEcce) (i.e., 3-sec-eccentric/1-sec-concentric) on subsequent countermovement jump performance.** Material and Methods. **Fourteen males recreationally trained participated this study. Participants alternately performed CAConc and CAEcce protocols in the leg press 45º and, after a 4-min recovery interval, performed three countermovement jumps. A 72-hour recovery interval was adopted between the protocols.** Results. **No significant difference in mean height and relative power of the countermovement jump among baseline and both protocols, as well as between CAConc and CAEcce (p > 0.05). However, percentage increases in mean height and relative power were observed between baseline and CAEcce (mean height: 1.36%/relative power: 2.25%), as well as between CAConc and CAEcce (mean height: 1.91%/relative power: 1.22%).** Conclusions. **CAEcce did not produce significant increases in the countermovement jump than CAConc, although greater percentage increases were observed for the CAEcce.**

KEYWORDS: countermovement jump, post-activation potentiation, concentric action, eccentric action, conditioning activity.

Received: 31 May 2021
Accepted: 23 August 2021

Corresponding author: reiclauy@hotmail.com

[1] *Federal University of Minas Gerais, Load Assessment Laboratory, Belo Horizonte, Brazil*
[2] *Federal University of Lavras, Studies Research Group in Neuromuscular Responses, Lavras, Brazil*
[3] *Federal University of Minas Gerais, Exercise Physiology Laboratory, Belo Horizonte, Brazil*
[4] *Federal University of São Paulo, Study Group and Research in Exercise Physiology, São Paulo, Brazil*
[5] *Federal University of Juiz de Fora, Postgraduate Program of the Faculty of Physical Education and Sports, Minas Gerais, Brazil*
[6] *Federal University of Lavras, Postgraduate Program in Nutrition and Health, Lavras, Brazil*

Introduction

The ability to develop power output in the lower limbs is considered a key factor for success in several sporting tasks such as sprint events [25], being decisive in jumping, kicking and sprint actions in team sports [31], as well as attack and defense in combat sports [17]. For this reason coaches and sports scientists are constantly looking for new approaches and verify their applicability to improve this ability [21]. The power output of the lower limbs may be enhanced through different warming strategies based on a high-intensity conditioning activity using half-squat [4, 8]. The increase in performance observed after a high-intensity conditioning activity is known as post-activation performance enhancement (PAPE) [14].

This phenomenon might be associated with the post-activation potentiation residue in its earliest stages after a conditioning activity, in addition to several other mechanisms, such as an increased temperature and muscle activation, as well as the shortening velocity triggered by the water content in the muscle fiber [6, 14, 37].

Boullosa [8] recently highlighted that several moderating factors such as type and exercise load, recovery interval and timing should be considered in order to better individualize and implement PAPE protocols. Furthermore, other factors such as the manipulation of eccentric muscle action have been shown to be effective in inducing PAPE when compared to the control [5] and traditional resistance training groups [4] during countermovement jump. To perform the eccentric action, these studies generally use flywheel devices combined with the half-squat [4, 5, 16]. Nevertheless, these devices are costly, making the application of this warming strategy unfeasible for most athletes. Alternatively, Wilk et al. [37] investigated the effects of different eccentric durations (medium: 2-sec and slow: 6-sec) on power output and bar velocity during three sets of the bench press exercise. Those authors concluded that PAPE effects were observed for both times of movement [37]. However, the effects of concentric duration on PAPE have not yet been clarified. Although the effects of repetition duration on resistance training have already been reported in terms of muscle strength [15], they are still limited with regard to PAPE [37], making it difficult to prescribe this variable during previous conditioning activity. Furthermore, Krzysztofik et al. [22] stated that little attention has been paid to the potential effect of PAPE on training volume. To achieve the desired training volume, performance of a certain number of repetitions (REP) per set, per exercise and per session can significantly affect adaptive changes induced by resistance training [24]. However, the duration of a single REP is not always the same, being dependent on the movement time used. In this way, in addition to the number of REP performed in a set or in an whole training session, the time under tension (TUT) is considered an important variable to describe the training volume [24]. According to Wilk et al. [34, 38], TUT during resistance exercise is a more accurate and reliable indicator of the training volume compared to the number of REP performed. To date, only two studies have examined the effect of PAPE on the volume of upper body resistance training, but only one of them considered TUT. Sevilmiş and Atalağ [33] observed a significantly increased REP number and TUT during a single set of bench press exercise performed until voluntary failure at 65% 1RM after a conditioning activity with eccentric actions at 120% 1RM compared to the control conditions. Moreover, Alves et al. [2] also reported an improvement in the training volume assessed by the total lifted load (REP × load) and the maximum number of REP performed after a conditioning activity.

Thus, the present study aimed to compare two different repetition durations: a) Conditioning Activity Concentric (CAConc) (i.e., 1-sec-eccentric/3-sec-concentric), and b) Conditioning Activity Eccentric (CAEcce) (i.e., 3-sec-eccentric/1-sec-conconcentric) on subsequent countermovement jump performance. Based on a previous study [37], the authors’ hypothesized that the CAEcce protocol would induce greater improvements in the countermovement jump performance than the CAConc protocol.

Material and Methods

Experimental design

A randomized, cross-over study design was adopted to verify the effects of the CAConc and CAEcce protocols on the subsequent countermovement jump (CMJ) performance. Each participant visited the laboratory four times separated by a 72-hour interval (Figure 1). During the first visit participants were familiarized with the CMJ and the experimental protocols. The familiarization with CMJ consisted of five sets of three jumps, while the experimental protocols consisted of one set of ten repetitions at 50% 1RM estimated. During the second visit participants were subjected to anthropometric assessments, CMJ baseline, and one-repetition maximum test (1RM) in the leg press 45° (LP45). In the third and fourth experimental sessions

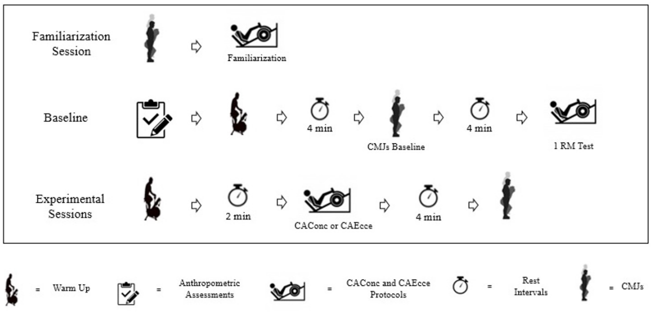

Figure 1. Experimental design

Note: CAConc – Conditioning Activity Concentric; CAEcce – Conditioning Activity Eccentric; CMJs – countermovement jumps; 1RM – one repetition maximum after a 5-min warm-up on the ergometer cycle at a self-selected intensity, participants performed the CAConc or CAEcce protocols and after the next 4-min rest interval they were subjected to performance assessment using CMJ tests.

Participants

Fourteen recreationally-trained males participated in this study (mean ± SD: age 20.6 ± 1.8 years; height 1.74 ± ± 6.1 m; body mass 74.6 ± 7.3 kg; body fat 10.2 ± 5.2 %; 1RM 331.0 ± 56.8 kg). To be volunteers in the study, participants needed to have a minimum experience of six months in resistance training with a weekly frequency of at least three times a week. All participants who had any health problems and/or bone, joint and muscular disorders that could affect their ability to complete the study protocol were previously excluded. Furthermore, all participants were instructed not to perform strenuous exercise and not to take caffeine or any nutritional supplement before testing. Before the study participants signed a consent form previously approved by the local human research ethics committee (CAAE: 59466616.5.0000.5148) in accordance with the Declaration of Helsinki.

Anthropometric assessments

A scale with a stadiometer was used to measure the height and body mass of the participants (110 FF, Welmy®, Santa Bárbara d'Oeste, Brazil). Body fat was determined using a B-mode ultrasound system (Bodymetrix pro System, Intelametrix®, Livermore, USA).

One repetition maximum testing

The 1RM testing was assessed using an LP45 inclined press (Physicus®, Auriflama, Brazil). For the 1RM testing participants attended the laboratory at the same time as the experimental sessions and performed a 5-min warm-up on a cycle ergometer at a self-selected intensity. Subsequently, participants performed 15, 10, and 5 repetitions using loads corresponding to 20, 50, and 70% of their self-reported 1RM. Thereafter, the first testing load was adjusted to an estimated 80% 1RM and increased by 2.5 to 5 kg in each trial until failure, using a 5-min recovery interval after each successful trial following Wilk et al. [35], who used this protocol during the bench press. Between 1 and 3 repetitions were used for a maximum of 5 trials until participants were able to perform only one repetition maximum. The LP45 was started with the knees semi-extended and then participants performed the eccentric phase of the movement until their knees were at approximately 90° of flexion. Afterwards participants performed the concentric phase and returned to the initial phase of semi-extension of the knees. The technique of performing the exercise was verified by a single experienced evaluator and feedback was provided to the participant throughout the trials. During the testing movement speed (cadence) was maintained at (2/0/1/0), i.e. a 2-s eccentric phase, 0-s (no break in the transition phase), a 1-s concentric phase and 0-s (no rest before the next repetition) [34] using a digital metronome (DM90, Seiko®, Tokyo, Japan).

Conditioning activity protocols

Both protocols (CAConc and CAEcce) were performed in the LP45. Before starting each protocol participants performed a standard warm-up on a cycle ergometer (5-min at a fixed speed of 60 rpm with a load corresponding to 50 Watts). Next, participants performed 3 sets of 5 repetitions on the LP45 using loads adjusted to 70% 1RM [37] with two different repetition durations: 1) CAConc: (3/0/1/0), i.e. a 1-s eccentric phase, 0-s (no break in the transition phase), a 3-s concentric phase, and 0-s (no rest before the next repetition), and 2) CAEcce: (1/0/3/0), i.e. a 3-s eccentric phase, 0-s (no break in the transition phase), a 1-s concentric phase, and 0-s (no rest before the next repetition) [34]. The recovery interval between the protocols with the respective conditioning activity and the countermovement jumps was 4 minutes according to Hughes et al. [20], who used this protocol during the back squat.

Countermovement jump

To measure the countermovement jump performance (height jump and relative power) in both protocols participants performed CMJ testing [7] using a contact platform (Cefise®, Nova Odessa, Brazil) interconnected to a software (version 1.0; Jump System). Participants performed three CMJs with a 15-sec rest interval between attempts. Coefficients of variation (CV) ranged from 0.6 to 1.4%. To exclude the influence of arm-swing, participants were instructed to keep their hands on their hips during attempts. The mean for the three CMJs was calculated and used to determine the performance [10]. The Intraclass Correlation Coefficients (ICCs) for the day-to-day reproducibility of the dependent performance measures were recorded at ICCs ≥0.95.

Statistical analysis

The data are presented as means ± standard deviations. The normality of the data was assessed using the Shapiro–Wilk test. A one-way ANOVA with repeated measures and Bonferroni’s post-hoc were used to compare the baseline and the protocols (i.e. CAConc and CAEcce). The effect size was assessed using the following criteria: ≤0.40, 0.41-0.80, and >0.80, being interpreted as small, moderate and large, respectively, according to Cohen [11]. As statistical evidence, a significance level (α) of 5% was adopted using the SPSS statistical software (version 25.0; IBM Corp, Armonk, NY).

Results

The 1RM, loads and density were the same for both variants and are shown in Table 1.

Table 1. Training load variables

Variables	Mean
1RM	331.0 kg
Load	231.7 kg
Density	0.06

Note: 1RM – one repetition maximum

No significant difference was found in mean height of the countermovement jump ($p > 0.05$) between CAConc (36.6 ± 5.9 cm), CAEcce (37.4 ± 6.3 cm) and the baseline (36.8 ± 5.7 cm) (Figure 2). Moreover, a trivial effect size was found between the baseline, CAConc and CAEcce in the mean height of the countermovement jump (Table 2).

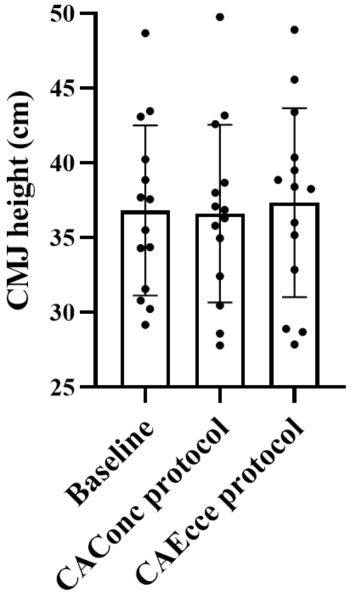

Figure 2. Comparison of mean height of the countermovement jump among baseline and conditioning activities protocols

Note: CAConc – Conditioning Activity Concentric; CAEcce – Conditioning Activity Eccentric; CMJ – countermovement jump

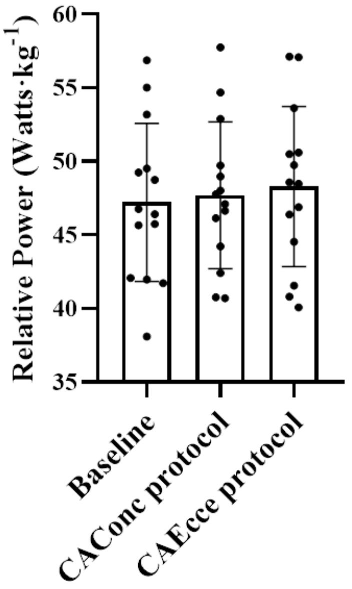

Figure 3. Comparison of relative power of the countermovement jump among baseline and conditioning activities protocols

Note: CAConc – Conditioning Activity Concentric; CAEcce – Conditioning Activity Eccentric

Table 2. Δ%, effect size (d), and p values in mean height of the countermovement jump for baseline, CAConc, and CAEcce

Protocols	Δ%	Cohen’s (d)	(p) values
CAConc – baseline	–0.54%	–0.03	0.563
CAEcce – baseline	1.36%	0.08	0.347
CAEcce – CAConc	1.91%	0.11	0.679

Note: CAConc – Conditioning Activity Concentric; CAEcce – Conditioning Activity Eccentric

Table 3. Δ%, effect size (d), and p values in relative power of the countermovement jump among baseline, CAConc, and CAEcce

Protocols	Δ%	Cohen’s (d)	(p) values
CAConc – baseline	1.02%	0.07	0.458
CAEcce – baseline	2.25%	0.18	0.287
CAEcce – CAConc	1.22%	0.11	0.699

Note: CAConc – Conditioning Activity Concentric; CAEcce – Conditioning Activity Eccentric

No significant difference was found in mean relative power of the countermovement jump ($p > 0.05$) between CAConc (47.6 ± 5.0 watts · kg^{-1}), CAEcce (48.3 ± ± 5.6 watts · kg^{-1}) and the baseline (47.2 ± 5.4 watts · kg^{-1}) (Figure 3). Furthermore, a trivial effect size was found between the baseline, CAConc and CAEcce in relative power of the countermovement jump (Table 3).

Discussion

The main findings of the present study refuted the authors' initial hypothesis, indicating that there was no significant difference in mean height and relative power of the countermovement jump between the baseline and both protocols, as well as between CAConc and CAEcce. On the other hand, percentage increases in mean height and relative power were observed between the baseline and CAEcce, as well as between CAConc and CAEcce.

Eccentric exercises have been used as a conditioning activity to enhance performance in the countermovement jump, presenting opposite results [4, 5, 16, 20, 37]. Beato et al. [5] verified that 3 sets of 6 repetitions in the half-squat performed on a flywheel device improved countermovement jump performance (i.e. height, peak power, impulse and peak force) compared to traditional warm-up (i.e. cycle ergometer) in male athletes. However, when the same protocol using a flywheel device was compared to the traditional weightlifting half-squat, the results showed no difference between the protocols in the countermovement jump performance [4]. Using a simple protocol to accentuate the eccentric load through 6 drop jumps without the propulsive phase and with the standardized box height at 60-cm, Hughes et al. [20] found significant improvements in the countermovement performance compared to a traditional half-squat protocol. These results are further supported by findings of Wilk et al. [35], who showed that different eccentric durations yielded a PAPE effect during the bench press. Although we did not use an essentially eccentric protocol in the present study, in percentage terms the authors' results indicated that the repetition duration with an emphasis on the eccentric phase showed a greater percentage PAPE effect compared to the emphasis on the concentric phase.

Physiologically, it seems that one of the main mechanisms for post-activation potentiation may be associated with increases in the recruitment of fast-twitch motor units [19]. Ojasto and Häkkinen [29] showed greater increases in blood lactate concentrations when higher eccentric loads were used. This progressive increase in blood lactate concentrations as a function of the magnitude of the eccentric load provides strong evidence for the recruitment of fast glycolytic muscle fibers [20]. In parallel, the subsequent performance might be enhanced as exercise with an eccentric overload is introduced into the conditioning activities, possibly due to the muscular stretching provided by the eccentric actions [20], which might increase synchronization of the motor units leading to an improved power output [28]. These hypotheses may be partially justified by the close relationship found between eccentric peak force and countermovement jump height [9]. Furthermore, it has been reported that the production of eccentric force is dependent on the number of active actin-myosin cross-bridges [18]. Therefore, any post-activation potentiation mechanism such as phosphorylation of myosin light chains that allows their heads to move closer to the actin binding sites [1], making it more sensitive to Ca^{+2} availability [37], may increase the rate of cross-bridge formation [27] and improve the contraction in movements involving the stretch-shortening cycle [13].

Although the CAEcce protocol caused only percentage changes in mean height and relative power of the countermovement jump compared to the baseline and the CAConc protocol (Table 2, Table 3), minor changes in the jump performance may represent a real improvement and be sensitive to post-activation potentiation mechanisms. In this line, if we consider that the coefficient of variation for the countermovement jump of professional athletes is around 1.6% [3] and take into account that this individual characteristic presents a low smallest worthwhile change [12], the percentage increases found in the authors' study might at least be considered important. In addition, the authors' results also suggest that the repetition duration with an emphasis on the concentric phase seems to attenuate performance in the subsequent countermovement jump. These results may be potentially important for prescribing repetition duration during a conditioning activity, where coaches should prioritize a slower eccentric phase and a faster concentric phase, although further studies on the repetition duration in conditioning activity are still needed to confirm this claim.

Wilk et al. [36] showed that a different distribution of movement tempo during a set of resistance exercises has a significant impact on power performance of the upper limbs. The use of slow repetitions at the beginning of a set, with longer TUT, may be effective in stimulating muscle strength and hypertrophy. However, the possibility of using a slow movement tempo, particularly in the concentric action, is limited by external load. Therefore, the use of a slow movement tempo causes a decrease in external load, which may reduce strength gains following long-term resistance training. Previous studies indicated that heavier loads produce greater strength gains than lighter loads, although the movement speed could be faster [32]. In this case, athletes could consider using a slow movement tempo in the first repetition only in the eccentric action, using a fast or explosive tempo in the concentric phase of movement (e.g. 6/0/X/0). For power development the training with the intention of moving the load explosively is believed to be optimal for power adaptations, irrespective of the contraction type, load or actual movement speed of the exercises used. Therefore, the use of slow repetition will reduce the movement speed, which will have a significant negative effect on acute power output and, as a consequence, may potentially limit the possibilities of power development. The use of different movement tempo distributions during a set may be useful, mainly during complex resistance training [39]. The slow movement tempo in the first repetition (which will cause an increase in muscle activation and lengthen TUT) and an explosive movement in the next repetitions (which will increase concentric speed) should be optimal both for hypertrophy development and power output. It is also possible to use an inverse tempo distribution to those presented in this study, where fast repetitions will be performed at the beginning of the set and slow repetitions at the end of the set. Such complex resistance training may be an effective alternative compared with traditional resistance protocols, especially when the time to perform specific resistance training goals is limited.

For the emphasis on the eccentric phase during the conditioning activity to significantly enhance subsequent performance, it may be necessary to apply heavier loads in the strength exercise (i.e. >70% 1RM), since essentially eccentric training requires supramaximal training loads in PAPE protocols [30]. However, several factors such as conditioning activity, training status, volume and intensity may interfere in the balance between fatigue and post-activation potentiation and influence the disparities found in the results of the studies [26]. Krzysztofik et al. [23] evaluated changes in power output and bar velocity in the bench press throw (BPT) following the bench press as a conditioning activity with concentric only (CONONLY) and eccentric only (ECCONLY) actions. Participants performed 2 sets of 2 repetitions using the bench press as a conditioning activity at 90% 1RM ECCONLY, 90% 1RM CONONLY, 110% 1RM ECCONLY, or 130% 1RM ECCONLY. The BPT was performed to assess changes in peak power, mean power and peak velocity, mean velocity before and after conditioning activity. This study demonstrated that the conditioning activity with ECCONLY movement at 110% and 130% 1RM significantly increased power output and bar velocity during the BPT, which may improve performance in explosive sports activities. Furthermore, the application of partial movement sequences during resistance training sessions may introduce new, additional stages of periodization in the development of power output, which opens opportunities for modification of strength training programs, particularly in elite strength-trained athletes. Partial movement sequences (ECCONLY) may be effective in short-term power output development, but only when the load used in the conditioning activity exceeds 100% 1RM. Partial movements with loads below 1RM may be insufficient to elicit the PAPE effect in strength-trained individuals. However, it should be stressed that these results and training suggestions apply primarily to elite athletes with a high level of muscular strength and extensive experience in resistance training at the use of loads above 100% 1RM.

As a practical application, power sports athletes could use a slower eccentric phase in combination with a more explosive concentric phase during their conditioning activity. This combination could potentially be important to improve explosive performance, specifically when the conditioning activity is performed with submaximal lifting loads.

Conclusions

The present study demonstrated that repetition duration with an emphasis on eccentric action during the conditioning activity did not significantly increase the mean height and relative power of the countermovement jump, although there were percentage increases compared to the emphasis on concentric action. Furthermore, the emphasis on concentric action seems to decrease performance during the countermovement jump.

Conflict of Interests

The author declares there was no conflict of interest.

References

1. Alamo L, Li XE, Espinoza-Fonseca LM, Pinto A, Thomas DD, Lehman W, et al. Tarantula myosin free head regulatory light chain phosphorylation stiffens N-terminal extension, releasing it and blocking its docking back. Mol Biosyst. 2015;11(8):2180-2189. https://doi.org/10.1039/c5mb00163c.
2. Alves RR, Viana RB, Silva MH, Guimarães TC, Vieira CA, Santos DAT, Gentil PRV. Postactivation potentiation

improves performance in a resistance training session in trained men. J Strength Cond Res. 2021;35(12):3296--3299. https://doi.org/10.1519/JSC.0000000000003367.

3. Balsalobre-Fernández C, Tejero-González CM, del Campo-Vecino J. Relationships between training load, salivary cortisol responses and performance during season training in middle and long distance runners. PloS One. 2014;9:e106066.
4. Beato M, Bigby AEJ, De Keijzer KL, Nakamura FY, Coratella G, McErlain-Naylor SA. Post-activation potentiation effect of eccentric overload and traditional weightlifting exercise on jumping and sprinting performance in male athletes. PLoS One. 2019; 14(9): e0222466. https://doi.org/10.1371/journal.pone. 222466.
5. Beato M, Stiff A, Coratella G. Effects of postactivation potentiation after an eccentric overload bout on countermovement jump and lower-limb muscle strength. J Strength Cond Res. 2021;35(7):1825-1832. https://doi.org/10.1519/JSC.0000000000003005.
6. Blazevich AJ, Babault N. Post-activation potentiation versus post-activation performance enhancement in humans: historical perspective, underlying mechanisms, and current issues. Front Physiol. 2019;10:1359. https://doi.org/10.3389/fphys.2019.01359.
7. Bosco C, Luhtanen P, Komi PV. A simple method for measurement of mechanical power in jumping. Eur J Appl Physiol Occup Physiol. 1983;50(2):273-282. https://doi.org/ 10.1007/BF00422166.
8. Boullosa D. Post-activation performance enhancement stragies in sport: A brief review for practitioners. Hum Mov. 2021;22(3):101-109. https://doi.org/10.5114/hm.2021.103280.
9. Bridgeman LA, McGuigan MR, Gill ND, Dulson DK. Relationships between concentric and eccentric strength and countermovement jump performance in resistance trained men. J Strength Cond Res. 2018;32(1):255-260. https://doi.org/10.1519/JSC.0000000000001539.
10. Claudino JG, Cronin J, Mezêncio B, McMaster DT, McGuigan M, Tricoli V, et al. The countermovement jump to monitor neuromuscular status: a meta-analysis. J Sci Med Sport. 2017;20(4):397-402. https://doi.org/10.1016/j.jsams.2016.08.011.
11. Cohen J. Statistical power analysis for the behavioral sciences. Academic Press; 2013.
12. Cormack SJ, Newton RU, McGuigan MR, Doyle TL. Reliability of measures obtained during single and repeated countermovement jumps. Int J Sports Physiol Perform. 2008;3(2):131-144. https://doi.org/10.1123/ijspp.3.2.131.
13. Cormie P, McGuigan MR, Newton RU. Changes in the eccentric phase contribute to improved stretch-shorten cycle performance after training. Med Sci Sports Exerc. 2010;42(9):1731-1744. https://doi.org/10.1249/MSS.0b013e3181d392e8.
14. Cuenca-Fernández F, Smith IC, Jordan MJ, MacIntosh BR, López-Contreras G, Arellano R, et al. Nonlocalized postactivation performance enhancement (PAPE) effects in trained athletes: a pilot study. Appl Physiol Nutr Metab. 2017;42(10):1122-1125. https://doi.org/10.1139/apnm-2017-0217.
15. Davies TB, Kuang K, Orr R, Halaki M, Hackett D. Effect of movement velocity during resistance training on dynamic muscular strength: a systematic review and meta-analysis. Sports Med. 2017;47(8):1603-1617. https://doi.org/10.1007/s40279-017-0676-4.
16. de Keijzer KL, McErlain-Naylor SA, Dello Iacono A, Beato M. Effect of volume on eccentric overload-induced postactivation potentiation of jumps. Int J Sports Physiol Perform. 2020;28:1-6. https://doi.org/10.1123/ijspp.2019-0411.
17. de Quel ÓM, Ara I, Izquierdo M, Ayán C. Does physical fitness predict future karate success? A study in young female karatekas. Int J Sports Physiol Perform. 2020;15(6):868-873. https://doi.org/10.1123/ijspp.2019-0435.
18. Enoka RM. Eccentric contractions require unique activation strategies by the nervous system. J Appl Physiol. 1996;81(6):2339-2346. https://doi.org/10.1152/jappl.1996.81.6.2339.
19. Güllich A, Schmidtbleicher D. MVC-induced short-term potentiation of explosive force. New Stud Athlet. 1996; 11:67-84.
20. Hughes JD, Massiah RG, Clarke RD. The potentiating effect of an accentuated eccentric load on countermovement jump performance. J Strength Cond Res. 2016;30(12):3450-3455. https://doi.org/10.1519/JSC.0000000000001455.
21. Kobal R, Pereira LA, Kitamura K, Paulo AC, Ramos HA, Carmo EC, et al. Post-activation potentiation: is there an optimal training volume and intensity to induce improvements in vertical jump ability in highly-trained subjects? J Hum Kinet. 2019;66:195-203. https://doi.org/10.2478/hukin-2018-0071.
22. Krzysztofik M, Wilk M, Filip A, Zmijewski P, Zajac A, Tufano JJ. Can post-activation performance enhancement (PAPE) improve resistance training volume during the bench press exercise? Int J Environ Res Public Health. 2020;17(7):2554. https://doi.org/10.3390/ijerph17072554.
23. Krzysztofik M, Wilk M, Golas A, Lockie RG, Maszczyk A, Zajac A. Does eccentric-only and concentric-only activation increase power output? Med

Sci Sports Exerc. 2020;52(2):484-489. https://doi.org/10.1249/MSS.0000000000002131.

24. Krzysztofik M, Wilk M, Wojdała G, Gołaś A. Maximizing muscle hypertrophy: a systematic review of advanced resistance training techniques and methods. Int J Environ Res Public Health. 2019;16(24):4897. https://doi.org/10.3390/ijerph16244897.
25. Loturco I, Pereira LA, Cal Abad CC, D'Angelo RA, Fernandes V, Kitamura K, et al. Vertical and horizontal jump tests are strongly associated with competitive performance in 100-m dash events. J Strength Cond Res. 2015;29(7):1966-1971. https://doi.org/10.1519/JSC.0000000000000849.
26. Lowery RP, Duncan NM, Loenneke JP, Sikorski EM, Naimo MA, Brown LE, et al. The effects of potentiating stimuli intensity under varying rest periods on vertical jump performance and power. J Strength Cond Res. 2012;26(12):3320-3325. https://doi.org/10.1519/JSC.0b013e318270fc56.
27. Metzger JM, Greaser ML, Moss RL. Variations in cross-bridge attachment rate and tension with phosphorylation of myosin in mammalian skinned skeletal muscle fibers. Implications for twitch potentiation in intact muscle. J Gen Physiol. 1989;93(5):855-883. https://doi.org/10.1085/jgp.93.5.855.
28. Moore CA, Weiss LW, Schilling BK, Fry AC, Li Y. Acute effects of augmented eccentric loading on jump squat performance. J Strength Cond Res. 2007;21(2):372-377. https://doi.org/10.1519/R-18605.1.
29. Ojasto T, Häkkinen K. Effects of different accentuated eccentric loads on acute neuromuscular, growth hormone, and blood lactate responses during a hypertrophic protocol. J Strength Cond Res. 2009;23(3):946-953. https://doi.org/10.1519/JSC.0b013e3181a2b22f.
30. Ong JH, Lim J, Chong E, Tan F. The effects of eccentric conditioning stimuli on subsequent counter-movement jump performance. J Strength Cond Res. 2016;30(3):747--754. https://doi.org/10.1519/JSC.0000000000001154.
31. Pereira LA, Nimphius S, Kobal R, Kitamura K, Turisco LAL, Orsi RC, et al. Relationship between change of direction, speed, and power in male and female National Olympic team handball athletes. J Strength Cond Res. 2018;32(10):2987-2994. https://doi.org/10.1519/JSC.0000000000002494.
32. Schoenfeld BJ, Peterson MD, Ogborn D, Contreras B, Sonmez GT. Effects of low- vs. high-load resistance training on muscle strength and hypertrophy in well-trained men. J Strength Cond Res. 2015;29(10):2954--2963. https://doi.org/10.1519/JSC.0000000000000958.
33. Sevilmiş E, Atalağ O. Effects of post activation potentiation on eccentric loading: is it possible to do more repetitions after supra-maximal loading? J Hum Sport Exer. 2019;14(3): 584-590. https://doi.org/10.14198/jhse.2019.143.09.
34. Wilk M, Golas A, Stastny P, Nawrocka M, Krzysztofik M, Zajac A. Does tempo of resistance exercise impact training volume? J Hum Kinet. 2018;62:241-250. https://doi.org/10.2478/hukin-2018-0034.
35. Wilk M, Golas A, Zmijewski P, Krzysztofik M, Filip A, Coso JD, et al. The effects of the movement tempo on the one-repetition maximum bench press results. J Hum Kinet. 2020;72:151-159. https://doi.org/10.2478/hukin-2020-0001.
36. Wilk M, Jarosz J, Krzysztofik M, Filip-Stachnik A, Bialas M, Rzeszutko-Belzowska A, et al. Contrast tempo of movement and its effect on power output and bar velocity during resistance exercise. Front Physiol. 2021;11:629199. https://doi.org/10.3389/fphys.2020.629199.
37. Wilk M, Krzysztofik M, Drozd M, Zajac A. Changes of power output and velocity during successive sets of the bench press with different duration of eccentric movement. Int J Sports Physiol Perform. 2020;15(2):162--167. https://doi.org/ 10.1123/ijspp.2019-0164.
38. Wilk M, Krzysztofik M, Maszczyk A, Chycki J, Zajac A. The acute effects of caffeine intake on time under tension and power generated during the bench press movement. J Int Soc Sports Nutr. 2019;16(1):8. https://doi.org/10.1186/s12970-019-0275-x.
39. Wilk M, Tufano JJ, Zajac A. The influence of movement tempo on acute neuromuscular, hormonal, and mechanical responses to resistance exercise: a mini review. J Strength Cond Res. 2020;34(8):2369-2383. https://doi.org/10.1519/JSC.0000000000003636.