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ORIGINAL RESEARCH

Electromyographic responses during isometric contraction in post-activation potential protocol

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Abstract

Post-activation potentiation (PAP) has recently emerged as a pivotal phenomenon representing an acute enhancement in performance by significantly increasing muscle strength. The aim of this study was to investigate the effect of PAP on the median and peak values of vastus lateralis, vastus medialis, and rectus femoris muscles during isometric muscle contraction using electromyography (EMG). The study involved 14 male amateur soccer players whose one-repetition maximum (1RM) values were determined in the initial session. A crossover design was employed, implementing both a PAP protocol consisting of one set of three repetitions at 85% of 1RM and a Non-PAP protocol consisting only of warm-up exercises. The median and peak values of maximal voluntary contraction (MVC) between groups (Non-PAP and Back-squat) were compared, employing the Mann-Whitney U test for intergroup comparisons. The results indicated no statistically significant differences in the median and peak values of the vastus lateralis, vastus medialis, and rectus femoris muscles between the Non-PAP and Back-squat groups. However, upon closer examination, it was observed that the median and peak EMG responses of the PAP group were higher compared to the Non-PAP group. These findings suggest that while PAP may not produce statistically significant changes in muscle activation in a small sample, there may still be a practical increase in muscle response following PAP, highlighting its potential benefit in enhancing performance.

Introduction

Warm-up protocols are important exercise forms for maximal power output and maximal strength development. These warm-up exercises can have positive or negative effects on subsequent muscle activity. One of the most notable warming strategies in recent years, post-activation potential (PAP), provides an acute increase in performance (Timon et al., 2019; de Freitas et al., 2021). It is noted that this acute increase occurs following a maximal or near-maximal pre-load stimulus (Tillin & Bishop, 2009; Blazevich et al., 2019). In the literature, this load corresponds to 80% of the 1RM maximum (Seitz et al., 2016). Another study demonstrated that a PAP protocol involving back squat exercise at 85% of one repetition maximum (1RM) improved vertical and horizontal jump performance (Evetovich et al., 2015). Additionally, the optimal time interval for PAP is reported to be between 3 to 9 minutes. In a systematic review and meta-analysis by Dobbs et al. (2019), it was reported that post-activation potentiation did not result in a significant increase in vertical jump performance. However, it was observed that rest intervals between 3 to 7 minutes supported performance enhancement. Timon et al. (2019) investigated the effects of two different PAP protocols on squat jump performance and observed a potential increase in squat jump performance at the 4th and 8th minutes following the Inertial Flywheel PAP protocol, unlike the traditional PAP protocol. When examining the literature, similar findings have been observed in PAP studies conducted using different exercise protocols and rest intervals (Byrne et al., 2014; Spieszny et al., 2022).

The most well-known physiological mechanism underlying PAP development is the increase in myosin regulatory light chain phosphorylation (Bauer et al., 2019). This process occurs through neurotransmitters creating an electrical change in the cell membrane and increasing the sensitivity of actin-myosin interaction to Ca2+ released from the sarcoplasmic reticulum. As a

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result, increased muscle contraction enables innervation of more muscle fibers by recruiting additional motor units, leading to an increase in power output (Macintosh et al., 2012). While an increase in muscle mass is a significant factor for power output, the development of intramuscular coordination is achieved through the simultaneous and high-frequency firing of motor units. This synchronization can be enhanced through strong muscle contractions.

Especially in the context of sport-specific contractions, monitoring power output involves various types of stimuli. The aim is to enhance maximal force obtained following maximal or near-maximal isometric or dynamic contractions (Esformes et al., 2011; Beato et al., 2021). In the study by Beato and colleagues, it was found that after eccentric overload, jump height, peak power, impulse, and peak force increased in male athletes along with the isokinetic strength of quadriceps and hamstrings. Similarly, many studies prefer to assess muscle strength using maximal voluntary isometric contraction (MVC). With this method, various variables such as isometric peak torque (IPT), contraction impulse (CI), rate of torque development (RTD), among others, can be tested (Andersen & Aagaard, 2006). In a study by Lima et al. (2014), it was demonstrated that the PAP protocol induced significant increases in isometric peak torque, contraction impulse, rate of torque development, and root mean square (RMS) values of the electromyographic (EMG) signal. Additionally, de Freitas et al. (2021) reported an approximately 9.8% increase in muscle force production during MVIC after 5 minutes of rest following PAP.

Tracking muscle activation through electromyography (EMG) is of great importance to measure power output in different PAP protocols. Surface electromyography is a suitable and non-invasive tool to examine skeletal muscle activation (Merletti & Lo Conte, 1997). The non-invasive nature of surface EMG has made it ideal for clinical use and research, and the repeatability of EMG data has been established for many isometric exercises (Türker & Sözen, 2013). EMG provides the opportunity to evaluate the acute effects of PAP on muscle strength by allowing quantitative and qualitative analysis of muscle activity in more detail (Uwamahoro et al., 2021). Thus, it can assist in identifying the most effective PAP strategies to optimize athletes' performance. Additionally, it may contribute to a better understanding of the biomechanical and neurophysiological foundations of PAP. The aim of this study was to investigate the effects of different pre-loading (PAP) protocols on muscle strength and muscle activation.

Methods

Subjects

The study included 14 male amateur soccer players (Age: 22.2 ± 2.04 years, height: 177.9 ± 5.36 cm, body mass: 73.4 ± 8.42 kg, and years of experience: 9.3 ± 3.19 years). Participants were aged between 18 and 25 and had been engaged in regular soccer training for at least three years. All individuals were free of injury for at least six months prior to the study. Before participating, the players were thoroughly briefed on the study's aims, procedures, and potential risks, and each provided written informed consent. The research was conducted in full compliance with the Declaration of Helsinki and received approval from the Ordu University of Clinical Research Ethics Committee (2024/58).

Design and Procedures

The athletes visited the laboratory for a total of 3 experimental sessions with a 48-hour interval between each session. The research utilized a randomized crossover design, where participants performed both a Post-Activation Potentiation (PAP) protocol and a Non-PAP protocol in separate sessions. The PAP protocol involved one set of three repetitions at 85% of their one-repetition maximum (1RM), while the Non-PAP protocol consisted of only warm-up exercises each session. Participants were required to have no lower extremity musculoskeletal injuries or any acute or chronic illness to be included in the study. In the first session, athletes were informed about the informed consent form and signed consent forms voluntarily to participate in the study. Anthropometric measurements and one-repetition maximum (1RM) back squat values were also obtained during the same session. Considering the chrono-biological rhythm, interventions were conducted at the same time of day, and participants were instructed not to consume any stimulant substances or alcohol within 12 hours before the sessions. In the subsequent second session, athletes underwent a 10-minute warm-up protocol consisting of 5 minutes of light jogging and 5 minutes of dynamic stretching exercises. After the warm-up, participants were subjected to a 5-second isometric strength test, and their muscle activations were monitored using electromyography (EMG) during the test. In the third session, a back squat PAP protocol consisting of 1 set of 3 repetitions at 85% of 1RM was applied, followed by a

4-minute rest, and muscle activations during the isometric strength test were monitored using the EMG method.

1 Repetition Maximum

During the first session, before performing the 1RM test, the athletes were given detailed information about the back squat exercise. After a 5-minute walk, they were subjected to a warm-up protocol consisting of 1 set of 10 repetitions with a weight corresponding to 50% of their estimated 1RM. During the 1RM test, the weight was gradually increased by 10-15% increments until the participants could no longer complete the movement (Gerose-Neto et al., 2016). All repetitions were performed with a 1-second eccentric and 1-second concentric contraction. The 1RM PAP protocol included a back squat exercise consisting of 1 set of 3 repetitions with a weight corresponding to 85% of the 1RM.

Isometric Strength Test Protocol

The athletes' isometric strength performances were tested using an isokinetic dynamometer (CSMI Humac Norm, Stoughton, USA). The isometric strength test was conducted with a concentric/concentric protocol at a 60° range of motion and lasted for 5 seconds. Prior to the test, all athletes were briefed theoretically, and the test was demonstrated practically to them. The isometric strength measurements specifically targeted the quadriceps muscle group, focusing on the vastus lateralis, vastus medialis, and rectus femoris muscles. The dominant leg was used for all tests, as determined by asking the participants which leg they used for kicking a soccer ball. The isometric strength performances of all athletes were tested once, with no additional rest provided after the test, as the testing session concluded following the completion of the isometric strength assessment.

Electromyography (EMG) measurement

A 16-channel surface EMG system (Noraxon Telemyo DTS System, Scottsdale, USA) was used to measure the activation rates of the rectus femoris (RF), vastus lateralis (VL), and vastus medialis oblique (VMO) muscles. Prior to electrode placement, the skin of each participant was shaved using a disposable razor and vigorously cleaned with alcohol until redness occurred to reduce skin impedance (Konrad, 2006). Bipolar Ag-AgCl surface electrodes (Noraxon Dual Electrodes) with a diameter of 2 cm were placed in pairs on the skin, with an inter-electrode distance of 2 cm parallel to the RF, VL, and VMO fibers. Electrode placement sites were determined according to the "Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM)" guidelines. EMG data were obtained from the dominant leg identified as the leg to kick the soccer ball (Zeller et al., 2003). Electrode placements and signal quality were verified by palpating the muscle during knee extension against resistance and visually inspecting the EMG signals. The sampling rate for EMG data was set at 1500 Hz. The test session synchronized with isometric force measurements of maximal voluntary isometric contraction (MVIC) for RF, VL, and VMO. MVIC determination lasted for 5 seconds (Larsen et al., 2014). All MVIC measurements were performed by the same evaluator. The evaluator verbally encouraged maximal performance during all MVICs. The obtained MVIC recordings were processed to calculate root-mean-square (RMS) average values using the software program of the same EMG system. Values were reported in microvolts (μV). The RMS value is used to measure muscle electrical activation as it reflects physiological activity in the motor unit during contraction (Fukuda et al., 2010). Therefore, a higher RMS value indicates greater muscle activation.

Data Analyses

In this study, SPSS (Statistical Package for the Social Sciences) software was used for data analysis. A significance level of $p<0.05$ was accepted for statistical analyses. The Shapiro-Wilk test was used to check whether the data conformed to normal distribution. Non-parametric tests were preferred for data that did not conform to normal distribution. Descriptive statistics of the study were presented as median, standard error, minimum, and maximum values. These data were compared between groups (Non-PAP and Back-squat) for median and peak values of maximal voluntary contraction (MVC). The Mann-Whitney U test was used for comparisons between groups. This test was applied to determine whether there were significant differences between the Non-PAP and Back-squat groups in the MVC median and peak values of the VL, VM, and RF muscles. Results were presented with median ranks, totals, and U and Z values.

Results

As shown in Table 2, no statistically significant difference was found between the median rank scores of vastus lateralis (VL), vastus medialis (VM), and rectus femoris (RF) muscles of the Non-pap (n=14) and back squat (n=14) groups (VL: U=87.000; Z=-0.505; p=0.613; VM: U=93.500; Z=-0.207; p=0.836; RF: U=87.500; Z=-

0.483; p=0.629). Similarly, there was no statistically significant difference found between the median rank scores of peak values of VL,VM, and RF muscles of the groups (VL: U=92.000; Z=-0.276; p=0.783; VM: U=90.000; Z=-0.368; p=0.713; RF: U=87.000; Z=-0.505; p=0.613).

Table 1
Descriptive characteristics of the study group (n=14).

Variables	Groups	Median	Std. Error	Min.	Maks.
MVC Median VL	Non-pap	440.500	20.11701	314.00	520.00
	Back-squat	448.500	28.10468	245.00	563.00
MVC Peak VL	Non-pap	558.500	29.03246	453.00	791.00
	Back-squat	601.500	34.70567	312.00	713.00
MVC Median VM	Non-pap	480.500	39.89756	360.00	836.00
	Back-squat	533.000	41.13288	288.00	823.00
MVC Peak VM	Non-pap	660.000	59.40322	457.00	1170.00
	Back-squat	720.500	50.36760	399.00	1027.00
MVC Median RF	Non-pap	523.500	40.79643	365.00	886.00
	Back-squat	586.500	49.26052	324.00	1017.00
MVC Peak RF	Non-pap	719.000	53.26152	529.00	1143.00
	Back-squat	821.000	69.04391	437.00	1398.00

MVC Median; Maximum voluntary contraction median value; MVC Peak: Maximum voluntary contraction peak value; VL: Vastus Lateralis; VM: Vastus Medialis; RF: Rectus Femoris; Min: Minimum; Max: Maximum.

Table 2
Comparison of the quadriceps muscle group median and peak values between groups.

Variables	Groups	Median Rank	Sum of Ranks	U	Z	P
MVC Median VL	Non-pap	13.71	192.00	87.000	-0.505	0.613
	Back-squat	15.29	214.00			
MVC Peak VL	Non-pap	14.93	209.00	92.000	-0.276	0.783
	Back-squat	14.07	197.00			
MVC Median VM	Non-pap	14.18	198.50	93.500	-0.207	0.836
	Back-squat	14.82	207.50			
MVC Peak VM	Non-pap	15.07	211.00	90.000	-0.368	0.713
	Back-squat	13.93	195.00			
MVC Median RF	Non-pap	13.75	192.50	87.500	-0.483	0.629
	Back-squat	15.25	213.50			
MVC Peak RF	Non-pap	13.71	192.00	87.000	-0.505	0.613
	Back-squat	15.29	214.00			

MVC Median: Maximum voluntary contraction median value; MVC Peak: Maximum voluntary contraction peak value; VL: Vastus Lateralis; VM: Vastus Medialis; RF: Rectus Femoris.

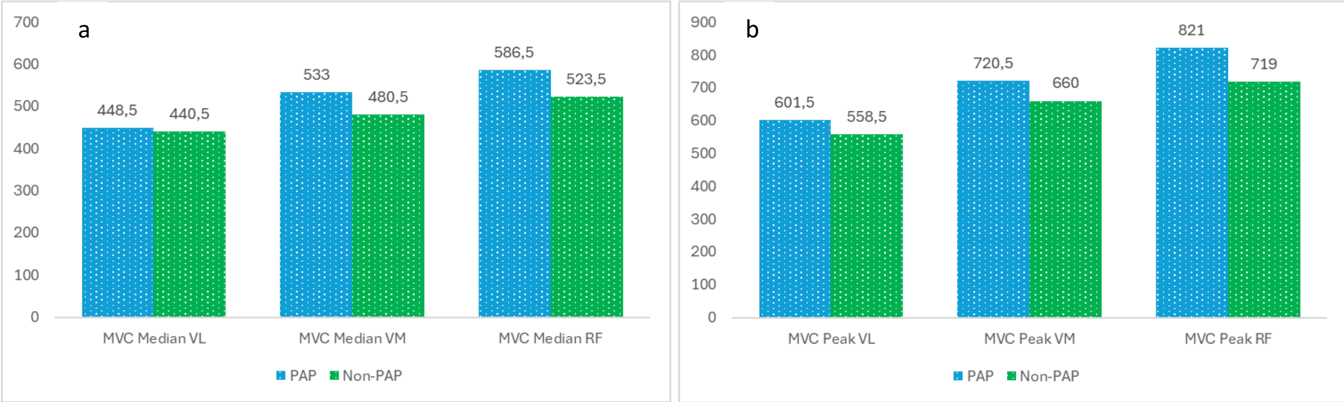

Figure 1. a) Median values in PAP and non-PAP Groups, b) Peak values in PAP and non-PAP Groups.

Discussion

In recent years, for sports such as football, basketball, volleyball, and athletics where maximal strength and explosiveness are particularly emphasized, maximal or near-maximal pre-loading training protocols are being implemented. This phenomenon, defined as post-activation potentiation (PAP), has been reported to enhance performance by inducing acute changes in the relevant muscle groups (Dobbs et al., 2019; Timon et al., 2019). In a study, it was reported that electromyographic activity responses were higher during weak muscle contractions following a brief intense pre-loading (Suzuki et al., 1988). In line with this result, it can be speculated that motor unit synchronization increases after an intense pre-loading exercise.

This study aimed to investigate the electromyographic responses during maximum isometric contractions with and without pre-loading. A crossover design was employed in the study. In the Non-PAP protocol, participants performed 5 minutes of light jogging and 5 minutes of dynamic stretching exercises. In the PAP protocol, following the warm-up, participants underwent pre-loading consisting of 1 set of 3 repetitions at 85% of 1RM in back squat, followed by 4 minutes of rest, and then underwent a 5-second isometric contraction. When examining Table 1, the descriptive characteristics including the median and peak variables of the vastus lateralis, vastus medialis, and rectus femoris muscles for each group, with their minimum and maximum values, are observed. Based on the findings of this study, no statistically significant difference was found in the median and peak values of the vastus lateralis, vastus medialis, and rectus femoris muscles between the groups.

In reviewing the literature, Masel & Maciejczyk (2022) investigated the effect of resistance trap bar deadlift with the same CA (conditioning activity) on squat jump (SJ) and countermovement jump (CMJ). When examining the results of the study, it was found that the PAP protocol did not improve jump performance in either SJ or CMJ, but significant differences were identified in individual analyses. Similarly, in another study, the effects of different PAP protocols on jump performance were investigated. Although a PAP protocol that improved jump performance was not identified in the study results, it was suggested that protocols performed with loads of 5 × 70 and 3 × 85 may have a high likelihood of causing significant changes in peak power and speed (Chaouachi et al., 2011). Dote-Montero et al. (2022) examined the effect of WB-EMS (whole-body electromyostimulation) combined with PAP to increase maximal isometric force. The maximum isometric force measurement results obtained at different minutes revealed that WB-EMS alone or combined with PAP did not provide a significant increase in maximum isometric force. However, it was noted that the combination of WB-EMS with PAP led to a significant increase of 54% at the 4th and 8th minutes. Among the key factors determining the PAP effect are not only the intensity and magnitude of the activity but also individual differences and rest periods. Balancing these factors correctly is crucial to achieve an effective PAP effect (Wilson et al., 2013). In their study, Wilson & colleagues found that potentiation occurred optimally with multiple sets, activities performed at moderate intensity, and moderate rest periods (7-10 minutes). Upon reviewing the literature, similar rest intervals for PAP effect are also supported by Dobbs et al. (2019).

In this study, the 4-minute rest interval provided after the PAP protocol did not yield a statistically significant difference in EMG responses. Although our study did not find a statistically significant difference between groups in the median and peak values of the quadriceps muscles, upon reviewing Table 2, it can be observed that the median and peak values of the PAP group were higher compared to the Non-PAP group. Similarly, this difference can be observed when examining Figure 1 and 2. Likewise, in a similar study, an increase in torque production was observed during maximum isometric knee extension without a change in electromyography (EMG) during (French et al., 2003). Jeon et al. (2001) examined whether the transfer ratios of knee flexion and extension affect subsequent quadriceps concentric activation and knee extension torque. The study results showed that as the rate of muscle contraction transfer increased, peak torque was significantly higher. Additionally, higher mean and peak values were observed for vastus medialis and vastus lateralis. Jeon and colleagues emphasized that these findings suggest an increase in quadriceps activation with eccentric preloading, indicating a rapid transfer from antagonist muscles to agonist muscles, thereby enhancing power development. In another study, significant increases in the rate of torque development (RTD) were observed following a 6-second maximum voluntary isometric contraction (MVC) (Baudry et al., 2007). Similarly, in a study, it was noted that protocols effective in inducing PAP involved 5-second MVCs, along with short-duration MVC and 6×5-MVC protocols resulting in higher twitch potentiation rates compared to continuous 30–60-second protocols (Skurvydas et al., 2019). In a study, the effect of loaded front squats (FSq) eccentric phase velocity on post-activation performance enhancement and whether FSq provides similar performance enhancements in knee and hip muscles was investigated. The study found that following a 2-second eccentric FSq, isokinetic strength increases were observed in hip extension, knee flexion, and hip flexion (Stastny et al., 2024).

The quadriceps muscle group located in the front of the legs, responsible for facilitating movements around the knee joint, plays a significant role in various sports activities such as running, jumping, and striking. Strengthening the quadriceps muscles is essential for performance enhancement in sports such as running, football, and wrestling. This strengthening not only contributes to the development of rapid and agile movements but also enhances power and stability. Achieving an acute increase, especially in sports where short-term maximal strength is prioritized, has become a priority for both athletes and coaches. Becoming an important strategy at this point, PAP can temporarily activate muscle fibers to a greater extent, leading to a short-term increase in power. A study investigating how different load levels during the barbell back squat affect muscle activation and coactivation found that higher loads (especially at 90% 1RM) during the ascent phase of the squat activate the muscles around the hips more (Martinez, Coons, & Mehls, 2023). These findings enhance the applicability of PAP protocols as an important loading strategy to enhance subsequent performance.

Considering the limitations of this study, it is important to note the limited sample size and the status of the sample group. A small sample size can affect the study's results and the generalizability of these results. Additionally, this study is limited to only EMG responses during isometric contractions. The generalizability of these findings to other types of contractions or exercise modalities may be affected. Furthermore, there is a limited number of studies on EMG responses of relevant muscle groups, which limits the understanding of the physiological mechanisms underlying the effects of PAP. In future studies, considering these limitations, more concrete findings can be obtained with a larger sample size and with more elite-level athletes.

Conclusion

This study suggests that post-activation potentiation (PAP) may positively influence isometric muscle contractions, as reflected by observed increases in EMG activity in the vastus lateralis, vastus medialis, and rectus femoris muscles following a front-loaded back squat at 85% of 1RM. While these changes did not reach statistical significance, the trends observed indicate a potential performance benefit from PAP. The absence of statistical significance may be attributed to factors such as sample size, variability in individual responses, or protocol design. Future research with larger sample sizes and refined methodologies is recommended to better elucidate the role of PAP in enhancing muscle activation and athletic performance.

Authors' Contribution

Study Design: Gİ, NA, TÇ; Data Collection: HS, MEÇ, NA, HAT; Statistical Analysis: Gİ, TÇ; Manuscript Preparation: HS, MEÇ, HAT.

Ethical Approval

The study was approved by the Ordu University of Clinical Research Ethics Committee (2024/58) and it was carried out in accordance with the Code of Ethics of the World Medical Association also known as a declaration of Helsinki.

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Conflict of Interest

The authors hereby declare that there was no conflict of interest in conducting this research.

References

Andersen, L. L., Aagaard, P. (2006). Influence of maximal muscle strength and intrinsic muscle contractile properties on contractile rate of force development. *Eur J Appl Physiol*, 96(1), 46-52.

Baudry, S., Duchateau, J. (1985). Postactivation potentiation in a human muscle: effect on the rate of torque development of tetanic and voluntary isometric contractions. *J Appl Physiol*, 102(4), 1394-1401.

Bauer, P., Sansone, P., Mitter, B., Makivic, B., Seitz, L. B., & Tschan, H. (2019). Acute effects of back squats on countermovement jump performance across multiple sets of a contrast training protocol in resistance-trained men. *J Strength Cond Res,* 33(4), 995-1000.

Beato, M., Stiff, A., & Coratella, G. (2021). Effects of postactivation potentiation after an eccentric overload bout on countermovement jump and lower-limb muscle strength. *J Strength Cond Res,* 35(7), 1825-1832.

Blazevich, A. J., & Babault, N. (2019). Post-activation potentiation versus post-activation performance enhancement in humans: historical perspective, underlying mechanisms, and current ıssues. *Front Physiol,* 10, 1359.

Byrne, P. J., Kenny, J., & O' Rourke, B. (2014). Acute potentiating effect of depth jumps on sprint performance. *J Strength Cond Res,* 28(3), 610–615.

Chaouachi, A., Poulos, N., Abed, F., Turki, O., Brughelli, M., Chamari, K., Drinkwater. E. J. & Behm, D. G. (2011). Volume, intensity, and timing of muscle power potentiation are variable. *Applied Physiology, Nutrition, and Metabolism*, 36(5), 736-747.

De Freitas, M. C., Rossi, F. E., Colognesi, L. A., De Oliveira, J. V. N. S., Zanchi, N. E., Lira, F. S., Cholewa, J. M., & Gobbo LA. (2021). Postactivation potentiation ımproves acute resistance exercise performance and muscular force in trained men. *J Strength Cond Res,* 35(5), 1357-1363.

Dobbs, W. C., Tolusso, D. V., Fedewa, M. V., & Esco, M. R. (2019). Effect of postactivation potentiation on explosive vertical jump: a systematic review and meta-analysis. *J Strength Cond Res,* 33(7), 2009-2018.

Dote-Montero, M., Pelayo-Tejo, I., Molina-Garcia, P., Carle-Calo, A., García-Ramos, A., Chirosa-Ríos, L. J., Chirosa-Ríos, I. J., & Amaro-Gahete, F. J. (2022). Effects of post-tetanic potentiation induced by whole-body electrostimulation and post-activation potentiation on maximum isometric strength. *Biol Sport,* 39(2), 451-461.

Esformes, J. I., Keenan, M., Moody, J., & Bampouras, T. M. (2011). Effect of different types of conditioning contraction on upper body postactivation potentiation. *J Strength Cond Res,* 25(1), 143-148.

Evetovich, T. K., Conley, D. S., & McCawley, P. F. (2015). Postactivation potentiation enhances upper- and lower-body athletic performance in collegiate male and female athletes. *J Strength Cond Res,* 29(2), 336-342.

French, D. N., Kraemer, W. J., & Cooke, C. B. (2003). Changes in dynamic exercise performance following a sequence of preconditioning isometric muscle actions. J *Strength Cond Res,* 17(4), 678-685.

Fukuda, T. Y., Echeimberg, J. O., Pompeu, J. E., Lucareli, P. R. G., Garbelotti, S., Gimenes, R. O., & Apolinário, A. (2010). Root mean square value of the electromyographic signal in the isometric torque of the quadriceps, hamstrings and brachial biceps muscles in female subjects. *J Appl Res,* 10(1), 32-39.

Gerosa-Neto, J., Rossi, F. E., Campos, E. Z., Antunes, B. M., Cholewa, J. M., & Lira, F. S. (2016). Impact of short and moderate rest ıntervals on the acute ımmunometabolic response to exhaustive strength exercise: Part II. *J Strength Cond Res,* 30(6), 1570-1576.

Jeon, H. S., Trimble, M. H., Brunt, D., & Robinson, M. E. (2001). Facilitation of quadriceps activation following a concentrically controlled knee flexion movement: the influence of transition rate. *J Orthop Sports Phys Ther,* 31(3), 122-132.

Konrad, P. (2005). *The abc of emg. A practical introduction to kinesiological electromyography*. Noraxon INC. USA.

Larsen, C. M., Juul-Kristensen, B., Olsen, H. B., Holtermann, A., & Søgaard, K. (2014). Selective activation of intra-muscular compartments within the trapezius muscle in subjects with subacromial ımpingement syndrome. A case-control study. *J Electromyogr Kinesiol,* 24(1), 58-64.

Lima, L. C. R., Oliveira, F. B. D., Oliveira, T. P., Assumpcao, C. D. O., Greco, C. C., Cardozo, A. C., & Denadai, B. S. (2014). Postactivation potentiation biases maximal isometric strength assessment. *Biomed Res Int*, 2014(1), 126961.

Martinez, S. C., Coons, J. M., & Mehls, K. D. (2023). Effect of external load on muscle activation during the barbell back squat. *Eur J Sport Sci,* 23(6), 975-982.

Masel, S., & Maciejczyk, M. (2022). Effects of post-activation performance enhancement on jump performance in elite volleyball players. *Appl. Sci,* 12(18), 9054.

Macintosh BR, Robillard ME, Tomaras EK. (2012). Should postactivation potentiation be the goal of your warm-up? *Appl Physiol Nutr Metab,* 37(3), 546-550.

Merletti, R., & Conte, L. R. L. (1997). Surface EMG signal processing during isometric contractions. *J Electromyogr Kinesiol,* 7(4), 241-250.

Seitz, L. B., Haff, G. G. (2016). Factors modulating post-activation potentiation of jump, sprint, throw, and upper-body ballistic performances: a systematic review with meta-analysis. *Sports Med,* 46(2), 231-240.

Skurvydas, A., Jurgelaitiene, G., Kamandulis, S., Mickeviciene, D., Brazaitis, M., Valanciene, D., Karanauskiene, D., Mickevicius, M., & Mamkus, G. (2019). What are the best isometric exercises of muscle potentiation? *Eur J Appl Physiol,* 119(4), 1029-1039.

Spieszny, M., Trybulski, R., Biel, P., Zając, A., & Krzysztofik, M. (2022). Post-ısometric back squat performance enhancement of squat and countermovement jump. *Int J Environ Res Public Health,* 19(19), 12720.

Stastny, P., Kolinger, D., Pisz, A., Wilk, M., Petruzela, J., & Krzysztofik, M. (2024). Effects of eccentric speed during front squat conditioning activity on post-activation performance enhancement of hip and thigh muscles. *J Hum Kinet,*15,91(Spec Issue), 5-18.

Suzuki, S., Kaiya, K., Watanabe, S., & Hutton, R. S. (1988). Contraction-induced potentiation of human motor unit discharge and surface emg activity. *Med Sci Sports Exerc,* 20(4), 391-395.

Tillin, N. A., & Bishop, D. (2009). Factors modulating post-activation potentiation and its effect on performance of subsequent explosive activities. *Sports Med,* 39(2), 147-166.

Timon, R., Allemano, S., Camacho-Cardeñosa, M., Camacho-Cardeñosa, A., Martinez-Guardado, I., & Olcina, G. (2019). Post-activation potentiation on squat jump following two different protocols: traditional vs. Inertial flywheel. *J Hum Kinet,* 69, 271-281.

Türker, H., & Sözen, H. (2013). Electrodiagnosis in New Frontiers of Clinical Research: Surface electromyography in sports and exercise (H. Turker, Ed.). InTech.

Uwamahoro, R., Sundaraj, K., & Subramaniam, I. D. (2021). Assessment of muscle activity using electrical stimulation and mechanomyography: a systematic review. *Biomed Eng Online,* 20(1). doi: 10.1186/s12938-020-00840-w.

Wilson, J. M., Duncan, N. M., Marin, P. J., Brown, L. E., Loenneke, J. P., Wilson, S. M., Jo, E., Lowery, R. P., & Ugrinowitsch, C. (2013). Meta-analysis of postactivation potentiation and power: effects of conditioning activity, volume, gender, rest periods, and training status. *J Strength Cond Res,* 27(3), 854-859.

Zeller, B. L., McCrory, J. L., Ben Kibler, W., & Uhl, T. L. (2003). Differences in kinematics and electromyographic activity between men and women during the single-legged squat. *Am J Sports Med,* 31(3), 449-456.