

Research Paper



Comparison of the Effectiveness of Traditional and Post-activation Potentiation Warm-up Methods on EMG Variables of Selected Lower Limb Muscles During Squat Jump

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ABSTRACT

Purpose: A proper warm-up method can be used as a strategy to improve the performance of athletes in various sports fields. The present study aimed to compare the effect of two traditional and post-activation potentiation (PAP) warm-up methods on electromyographic variables of lower limb muscles during squat jumps.

Methods: Fourteen trained male athletes randomly performed three different protocols: traditional warm-up method, dynamic Post-activation Potentiation (PD) by implementing two dynamic half-squat repetitions with 90% 1RM (one rep maximum), and static post-activation potentiation (PS) warm-up by implementing two static half-squat repetitions with 90% 1RM. Vertical jump tests were performed five minutes after implementing each protocol (recovery time). EMG activity of the rectus femoris, vastus lateralis, vastus medialis, biceps femoris, semi-tendinous, medial gastrocnemius, and tibialis anterior was recorded. Also, the co-contraction index and median frequencies were calculated. Repeated measures analysis of variance (ANOVA) was used for data analysis ($P < 0.05$).

Results: The results of this study showed that the activity level of all muscles in the concentric and flight phases, the co-contraction index of the ankle and knee joints, and also median frequencies of rectus femoris, vastus lateralis, semi-tendinous, biceps femoris, and medial gastrocnemius significantly changed in the PD and PS warm-up methods compared to the traditional warm-up method ($P \geq 0.05$). Also, the activity level of rectus femoris, vastus medialis, and biceps femoris muscles had a significant difference between the PD and PS compared to the traditional warm-up method in the eccentric phases ($P \geq 0.05$).

Conclusion: According to the study results, the PAP warm-up method can improve the performance of athletes in training and competition conditions.

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Highlights

- Post-activation potentiation phenomenon for a set of muscles has different effects in different positions.
- Post-activation potentiation phenomenon increased the co-contraction ratio of the knee and ankle joint muscles in the concentric phase.

Plain Language Summary

A proper warm-up method can be used as a strategy to improve performance of athletes in various sport fields. One of hybrid warm-up methods is post-activation potentiation warm-up method (PAP). This phenomenon includes any activity conducted with the aim to increase the ability of a muscle to generate more force. It seems that, the use of post-activation potentiation phenomenon in the warm-up process compared to traditional warm-up improves muscle performance and subsequently improves squat jump performance. Sport trainers are suggested adding a heavy strength-based conditioning exercise during the warm-up may help to increase their athletes' performance.

1. Introduction

Muscular strength and explosive performance play a vital role in many sports. In these movements, the quality and efficiency of implementation are critical [1]. Since athletes are always searching for ways to enhance their performance, it is crucial to evaluate and compare the ways to improve athletic performance. Many studies have also shown that maximum and submaximal muscle contractions can improve temporary muscle strength and jump performance. For instance, it has been suggested that vertical jump height performance can be improved due to increased muscle contraction [2]. Therefore, various methods have been used to increase jump performance through muscle strength. Warming-up is one of the significant factors that can improve athletic performance by increasing the temperature and energy metabolism of muscle, increasing the tissue elasticity, cardiac output, peripheral blood flow, and improving the performance of the nervous system and neuromuscular calling motor units [3].

Recent studies have shown that warming-up improves the implementation by increasing the force [4], high jump [5], speed [6], reducing reaction time, and increasing balance [7]. This improvement in implementation and performance after the warm-up is achieved by combining multiple neurological factors [8]. One of these factors may be the increased action potential production of the involved muscles which increases the compatibility, strength, the torque produced, speed, and ultimately more force.

Different types of exercises such as jumping, ballistic exercises, squats with heavy weights, and rapid movements have been increased with different warm-up methods [9]. A good warm-up method can be used as a mechanism to improve the performance of athletes in various sports. In this context, the squat jump is one of the most widely used sports gestures combined with 2-s maximum knee flexion (to eliminate sources of tension reflex in jump height). According to the principle of exercise specificity, specific warm-ups can be useful in enhancing coordination and improving performance by simulating the movements of a particular sport [9]. For example, improvement of rapid running [10] and jumping [11] after warm-up has been confirmed by many researchers.

One of the hybrid warm-up methods is the post-activation potentiation (PAP) warm-up method. This method is an enhanced neuromuscular state observed after performing a high-intensity exercise. PAP phenomenon includes any activity conducted to increase the muscle's ability to generate more force [11, 12]. This phenomenon is caused by maximal or near maximal exercises and increases neuromuscular performance [11]; as a result, it can have many applications, especially for warming up before speed-power sports [13]. Due to the significant interest of athletes and coaches in using this phenomenon in the warm-up phase and not too much research in this area, it seems necessary to examine the various aspects of this phenomenon. Also, research findings have been inconsistent about the effect of PAP, and this heterogeneity of the results in the scientific literature causes controversy about the effects of this phenomenon [14]. For example, in some studies, a significant change was observed in EMG activity of the quadriceps

muscles and also vertical jump performance while using the PAP method [15, 16]. However, some previous studies have shown that despite significant changes in performing a vertical jump, no significant change was observed in the electrical activity of the muscles of the knee while using this warm-up method [17, 18]. For example, Ghahremani et al., Abdolmaleki et al., French et al., and Jones et al., who used a high volume of loading and types of contractions, found no difference in the electrical activity of the muscles evaluated [17-20]. In general, these contradictions may be related to the research population or the implementation method, such as warming-up time or selecting a different load of one repetition maximum (1RM) which may impact the muscle strength. Thus, to improve the performance of professional athletes, identifying the differences in EMG of PAP phenomenon versus traditional warm-up seems necessary. Also, knowing the effects of EMG on the PAP phenomenon may show the effectiveness of this type of warm-up method on the better performance of athletic gestures. We hypothesized that a specific warm-up method could differently affect the electromyography activity of muscles compared to pre-exercise routines. Therefore, this study aimed to compare the effect of two traditional and PAP warm-up methods on the EMG variables of selected lower limb muscles in male athletes.

2. Materials and Methods

Study subjects

In this quasi-experimental study, based on G*Power software calculations, a sample consisting of at least 14 male-trained athletes was required to achieve a statistical power of 0.8 with an effect size of 0.8 at the significance level of 0.05. Participants' demographics were as follows: Mean±SD age: 26.5±3.64 years; Mean±SD height: 180±8.39cm; and Mean±SD weight: 70±10.65 kg. The subjects were athletes in track and field, soccer, volleyball, and basketball. They were healthy and had experience in regional competitions. They all had at least one year of resistance training experience, including the half-squat. During the last 4 months, they trained systematically 2-3 times per week with loads of 40%-90% of the 1RM aiming at power development [16]. The exclusion criteria were as follows: (a) history of neuromuscular, metabolic, hormonal, or cardiovascular disease, (b) use of any medication that could influence hormonal or neuromuscular function, and (c) any orthopedic limitation that could interfere with the performance of the test. Also, all participants provided consent to participate in the research and completed a health questionnaire at the beginning of the

work. All assessments were performed according to the principles of the Declaration of Helsinki.

Recording the electrical activity of muscles

A 16-channel wireless EMG system (Biomonitor ME6000, Kuopio, Finland) was used to record surface electromyography of the muscles of rectus femoris (RF), vastus lateralis (VL), vastus medialis (VM), biceps femoris (BF), semi-tendinous (ST), medial gastrocnemius (GM), and tibialis anterior (TA) of the dominant leg. The sampling frequency of the device was 2000 Hz. Ag/AgCl electrodes with a diameter of 10 mm in a dipole array were used to record the signal. Before connecting the electrodes, to reduce the resistance between skin and electrode, the muscle hair was shaved, and the area was cleaned with alcohol. The junction of electrodes and the muscles were identified by the European SENAIM protocol [21]. The electrodes were positioned at two-thirds on the line from the anterior superior iliac spine to the lateral side of the patella for VL, above the approximate midpoint of the distal half of muscle for VM, midway between the anterior superior iliac spine and the superior part of the patella for RF, midway between the ischial tuberosity and the lateral epicondyle of the tibia for BF, on the most prominent bulge of the muscle for GM, at 1/3 on the line between the tip of the fibula and the tip of the medial malleolus for tibialis anterior and 50% on the line between the ischial tuberosity and the medial epicondyle of the tibia for ST muscle. The ground electrode was attached to the tibia bone. To separate the different stages of the motion, two-foot switches which are sensitive to impact (one under the heel and the other on the metatarsal bone of the distal zone I) was used (Figure 1).

Procedures

The participants were referred to the lower limb biomechanics laboratory 72 hours before the start of the research process to determine one Repetition Maximum (1RM) in static and dynamic half squat motion. In this study, the Hoffman protocol was used [22]. Given the need for the subject's knee angle in static half squat motion of 90 degrees [23], the height of the squat base was set in a way that, when placing subjects in half squat, assistants should lift the weight 2 to 5 cm, so that the participants will be in an appropriate state. If the subjects could control a specific load for 4 s without disturbing the half-squat form, the weight load was increased after a break, according to the Hoffman Protocol. After determining the maximum static power of the subjects, it was used to determine the protocol load. The session for familiarity with protocols and tests was held at the



PHYSICAL TREATMENTS

Figure 1. Location of electrodes placement

session of determining one repetition maximum. The subjects participated in three sessions (72 hours) in the lab. In each session, three warm-up methods of the traditional method, post-activation potentiation warm-up method with dynamic motion of half squat with pair of feet with the intensity of 90% of one repetition maximum and, post-activation potentiation warm-up method with the static half squat with pair of feet with the intensity of 90% of one repetition maximum was randomly performed [18]. The subjects used a common general warm-up protocol with 3 different warm-up methods in every session, which initially ran at the speed of 9 mph for 5 minutes on the treadmill and then did stretching motions for 3 minutes (the quadriceps, hamstrings, front and back of the knee and the back and waist) (each for 4 to 6 seconds) and at the end, they performed the take-off [19, 23, 24]. After 5 minutes of completing the warm-up protocol (for rest), the subjects were in the half-squat state (knee angle between 90 and 100 degrees and legs open to the shoulder width size), and while the hands were held near the waist by saying the word “jump,” did the jump squat with maximum power and then came down with open knees [25].

Signal process

To analyze raw data obtained from surface electrodes, the Mega-Win software version 1.3 on the de-

vice and bandpass filter [10-500 Hz] were used. Data were analyzed from

400 ms before the foot switch with the ground to 400 ms after the contact with the ground during the landing stage. A fourth-order low-pass filter with a cutoff frequency of 10 Hz was used to smooth the signal. To normalize the data, muscle activity is divided by the muscle activity in the maximum voluntary isometric contraction (MVIC) test. Finally, the normalized muscle activity was evaluated in the three phases and expressed as a percentage of baselines [26]. The concentric phase was defined from the beginning to the peak, the flight phase from the peak to the eccentric phase, and the eccentric phase from the time of the collision of the feet to the off mode of leg muscle [27]. To determine the co-contraction in the two phases (concentric and eccentric), the formula provided by Anbarian et al. was used [28]. Co-contraction is used to investigate the simultaneous activity of different muscle groups to determine the interaction of agonist and antagonist muscles in a movement and strategy to use neuromuscular control in the motion.

The muscle activity of vastus medialis, rectus femoris, and vastus lateralis was used as agonist muscles, and biceps femoris and semi-tendinous muscles were used as the antagonist muscles for jumping to determine the extent of the knee joint co-contraction. For ankle joint muscle co-contraction, the medial gastrocnemius and tibialis anterior muscles were introduced as the agonist and antagonist muscles, respectively. In addition, the median frequency of muscle during the whole period of the motion (beginning of the concentric phase to the end of the eccentric phase) was calculated. To normalize the data of the median frequency, the highest median frequency in the MVIC test was used [29]. Since the median frequency is less sensitive to low-level noises and more sensitive to changes in the biochemistry and physiology factors during muscle contraction, this indicator was used to determine the contact speed of motor units and increase the force [30].

Statistical analysis

We used the Shapiro-Wilk test to determine whether a data set followed a normal distribution. Also, we used repeated measures ANOVA to examine the effects of the warm-up protocols on EMG activity. Significant differences between means were observed with Tukey's honestly significant difference (HSD) procedure ($P < 0.05$).

3. Results

Normalized activity of the muscles in the concentric phase

Results showed a significant difference in the normalized electrical activity of the selected muscles at the concentric phase between the three warm-up methods ($P \leq 0.01$); since the activity of lower limb muscles was significantly increased in the post-activation potentiation warm-up methods and the traditional warm-up method (Table 1).

Normalized activity of the muscles in the flight phase

Table 2 presents a significant difference in the normalized electrical activity of the selected muscles in

this phase in all warm-up methods ($P \leq 0.01$); therefore, by using post-activation potentiation warm-up methods (dynamic [PD] and static [PS]), the activity of the muscles of the lower limb increases significantly compared to the traditional warm-up methods. Only in rectus femoris muscle, no difference was observed between the static and dynamic post-activation potentiation warm-up methods.

The normalized activity of the muscles in the eccentric phase

The results showed a significant difference between the three warm-up methods in the normalized electrical activity of rectus femoris, vastus medialis, and biceps femoris muscles in this phase ($P \leq 0.01$) (Table 2). However, no significant differences were observed between

Table 1. Mean±SD of normalized electromyography activity from selected leg-dominant lower limb muscles during the concentric phase of different warm-up conditions

Muscles	Mean±SD		
	Traditional	Dynamic (PD)	Static (PS)
Rectus femoris	0.44±0.15*	0.55±0.17†*	0.65±0.31†*
Vastus lateralis	0.45±0.18*	0.63±0.29†*	0.85±0.29†*
Vastus medialis	0.52±0.25*	0.68±0.30†*	0.91±0.36†*
Semi-tendinous	0.13±0.40*	0.17±0.05†*	0.22±0.08†*
Biceps femoris	0.23±0.10*	0.28±0.14†*	0.38±0.16†*
Medial gastrocnemius	0.37±0.14*	0.49±0.18†*	0.58±0.16†*
Tibialis anterior	0.34±0.11*	0.41±0.12†*	0.53±0.17†*

PD: dynamic post-activation potentiation; PS: static post-activation potentiation.

PHYSICAL TREATMENTS

Significant difference $P < 0.01$ †*

Table 2. Mean±SD of normalized electromyography activity from selected leg-dominant lower limb muscles during the fly phase of different warm-up conditions

Muscles	Mean±SD		
	Traditional	Dynamic (PD)	Static (PS)
Rectus femoris	0.41±0.17*	0.46±0.19†	0.56±0.18†*
Vastus lateralis	0.39±0.19*	0.46±0.19†*	0.55±0.22†*
Vastus medialis	0.41±0.16*	0.48±0.19†*	0.61±0.24†*
Semi-tendinous	0.10±0.02*	0.12±0.03†*	0.15±0.05†*
Biceps femoris	0.20±0.09*	0.32±0.14†*	0.59±0.21†*
Medial gastrocnemius	0.32±0.10*	0.40±0.16†*	0.49±0.15†*
Tibialis anterior	0.18±0.07*	0.24±0.10†*	0.36±0.17†*

PD: dynamic post-activation potentiation; PS: static post-activation potentiation.

PHYSICAL TREATMENTS

Significant difference $P < 0.01$ †*

Table 3. Mean±SD of normalized electromyography activity from selected leg-dominant lower limb muscles during the eccentric phase of different warm-up conditions

Muscles	Mean±SD		
	Traditional	Dynamic (PD)	Static (PS)
Rectus femoris	0.22±0.09*	0.28±0.09†*	0.36±0.14†*
Vastus lateralis	0.29±0.11*	0.35±0.11*	0.46±0.16*
Vastus medialis	0.31±0.13*	0.39±0.16†*	0.48±0.19†*
Semi-tendinous	0.13±0.04*	0.17±0.05*	0.24±0.12*
Biceps femoris	0.30±0.13*	0.51±0.18†*	0.73±0.19†*
Medial gastrocnemius	0.27±0.10*	0.34±0.19†	0.43±0.18†*
Tibialis anterior	0.22±0.09*	0.36±0.20*	0.47±0.29*

PD: dynamic post-activation potentiation; PS: static post-activation potentiation.
 †* Significant difference P<0.01.

the different warm-up methods in the normalized activity of the vastus lateralis, semi-tendinous, and tibialis anterior muscles (P<0.01). Also, no significant difference was observed between the traditional and post-activation potentiation (PD) warm-up methods for medial gastrocnemius muscle (P<0.01) (Table 3).

Co-contraction of knee and ankle joint muscles

A significant difference was observed between the three warm-up methods in the co-contraction of the knee and ankle joint muscles at concentric and eccentric phases (P≤0.01). Also, a significant difference was observed between the three warm-up methods in muscle co-contraction ratio of knee joint muscles of concentric and eccentric phases (P≤0.01) (Table 4).

Normalized median frequency of selected muscles of lower extremities

The results showed a significant difference between the three warm-up methods in the median frequency middle

of rectus femoris, vastus lateralis, semi-tendinous, biceps femoris, and medial gastrocnemius muscles (P≤0.01). However, no significant difference was observed between the post-activation potentiation warm-up methods (PD) and (PS) in the normalized median frequency of vastus medialis and tibialis anterior (P<0.01) (Table 5).

4. Discussion

This study aimed to compare the effect of two traditional and PAP warm-up methods on EMG variables of selected lower limb muscles during squat jumps. According to Tables 1 to 3, a significant difference is observed in the activity of most of the muscles during the traditional and post-activation potentiation (PD and PS) warm-up methods. Based on these results, it seems that the increase in the muscle activity in the squat jump after post-activation potentiation warm-up (PD) may be due to the impact of transient recruitment of motor units and the creation of the compensation due to the reduction of the mechanical advantage of the muscles [31]. Also, implementing the PAP phenomenon for a set has

Table 4. Mean±SD Co-contraction of the knee and the ankle during concentric and eccentric phases in different warm-up conditions

Phases	Joint	Mean±SD		
		Traditional	Dynamic (PD)	Static (PS)
Concentric	Knee	0.52±0.19*	0.71±0.14†*	0.79±0.08†*
	Ankle	0.19±0.03*	0.30±0.11†*	0.43±0.12†*
Eccentric	Knee	0.61±0.11*	0.48±0.14†*	0.37±0.16†*
	Ankle	0.57±0.13*	0.42±0.18†*	0.29±0.17†*

PD: dynamic post-activation potentiation; PS, static post-activation potentiation.
 †* Significant difference P<0.01.

Table 5. Mean±SD of normalized median frequencies amount of selected leg-dominant lower limb muscles during different warm-up conditions

Muscles	Mean±SD		
	Traditional	Dynamic (PD)	Static (PS)
Rectus femoris	0.77±0.07*	0.85±0.06†*	0.94±0.08†*
Vastus lateralis	0.70±0.06*	0.78±0.06†*	0.90±0.11†*
Vastus medialis	0.83±0.06*	0.93±0.06*	0.98±0.09*
Semi-tendinous	0.75±0.12*	0.93±0.15†*	1.08±0.17†*
Biceps femoris	0.62±0.15*	0.75±0.18†*	0.85±0.24†*
Medial gastrocnemius	0.61±0.11*	0.71±0.11†*	0.77±0.12†*
Tibialis anterior	0.79±0.21*	0.98±0.21*	1.13±0.15*

PD: dynamic post-activation potentiation; PS: static post-activation potentiation.

†* Significant difference P<0.01.

different effects in different positions; since a significant difference was observed in some muscles and no significant differences were observed in others. This outcome is probably due to higher levels of muscle stimulation and more capacity for power generation [32]. Increased muscle activity in the flight phase during post-activation potentiation warm-up methods (PD and PS) may be due to the muscle ability to enhance the recruitment time of motor unit type 2 to increase the force and improve the performance [33]. Also, increased electrical activity in the eccentric phase can be stated as an intervention to reduce muscle and ligament damage during the landing [34]. Also, the significant increase in muscle at three motor phases during the PAP warm-up methods can be attributed to increased elastic and resilient energy storage while static squat and more activated muscles and non-contraction elements [35, 36].

The results showed significant differences between the three warm-up methods in the co-contraction of the knee and ankle joint muscles at concentric and eccentric phases. Since reducing co-contraction improves the efficiency of motion [37]; probably, the nervous system improves the upward movement of the center of gravity in a vertical jump by controlling multi-joint muscles, and thus the jump height may increase after post-activation potentiation warm-up (PD and PS methods) [35]. On the other hand, increasing co-contraction increases the joint pressure and also the stability of motion. According to the form of landing with straight knees in jumping, increasing co-contraction during the eccentric phase can be a reason for landing with more stability and joint pressure; while using the PAP phenomenon at the phase of

the warm-up, it is recommended to use suitable landing strategy in a squat jump to avoid extensive damages.

The results also showed a significant difference between the three warm-up methods in the median frequency of rectus femoris, vastus lateralis, semi-tendinous, biceps femoris, and medial gastrocnemius muscles. However, no significant difference was observed between the post-activation potentiation warm-up (PD and PS) in the normalized median frequency of vastus medialis and tibialis anterior. Due to an increase in median frequency during jump squats after both post-activation potentiation warm-up methods, the transfer speed of action potential may increase in sarcomere level, and this increase change and synchronize the cross-bridges; therefore, the production level of muscle strength increases, and its performance improves [29, 38-42]. Since the median frequency is susceptible to the changes within the muscle, it can be concluded that the PAP warm-up method increases the median frequency of the muscle and improves its performance by creating changes within the muscle.

The results of this study are consistent with the findings of Seydi et al. [15]. By applying loads of 40% and 80% of one repetition maximum in the warm-up and using the PAP phenomenon, they observed significant changes in the activity of rectus femoris, vastus lateralis, and vastus medialis muscles; however, in their study, they did not find significant differences in the activity of hamstring muscles, which is inconsistent with the findings of this study. This inconsistency can result from several factors. For example, the study subjects were adults, and maximum power was used in the potentiation method; while

the study participants of Saidi et al. (2015) were young athletes who probably reacted to PAP warm-up like those untrained and moderate and submaximal intensity was applied to them in PAP warm-up method. Also, the results of these studies were inconsistent with the findings of Ghahremani et al., Abdolmalik et al., and French et al. [17-19]. They reported that while improving the performance, the PAP warm-up has had no significant difference in the muscle activity examined; as a result, the reasons for improving the performance are related to intra-muscular factors and the three main mechanisms of post-activation potentiation. The difference between this study and those studies may be that in the analysis of the PAP phenomenon, they examined the electrical activity of muscles in a motor phase which can precisely hide the differences. With all these interpretations, according to many restrictions and a little research background on the multiple effects of the PAP warm-up method, future studies are required to determine the accuracy and efficiency of this warm-up method in sports and competition conditions. Identifying kinematic parameters may help to better interpret the results. This limitation should be considered in future studies.

5. Conclusion

According to our findings, the neuromuscular changes observed by surface electromyography can probably be the reason for the priority of the PAP warm-up method versus the traditional method. Thus, it seems that using the PAP phenomenon in the warm-up process improves muscle performance and subsequently improves squat jump performance compared to the traditional warm-up. Moreover, sports trainers are suggested to add a heavy strength-based conditioning exercise during the warm-up, which may help increase their athletes' performance during the competition.

Ethical Considerations

Compliance with ethical guidelines

All ethical principles are considered in this article. The participants were informed of the purpose of the research and its implementation stages. They were also assured about the confidentiality of their information and were free to leave the study whenever they wished, and if desired, the research results would be available to them. A written consent has been obtained from the subjects. principles of the Helsinki Convention was also observed.

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Authors' contributions

The authors equally contributed to the preparation of the article.

Conflict of interest

The authors declared no conflict of interest.

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