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The Effects of Different Stretching Techniques Used in Warm-Up on the Triggering of Post-Activation Performance Enhancement in Soccer Players

Kemal Kurak [1], İsmail İlbak [2], Stefan Stojanović [3], Ramazan Bayer [4], Tijana Purenović-Ivanović [3], Tomasz Pałka [5], Tadeusz Ambroży [6], Krzysztof Kasicki [7,*], Wojciech Czarny [8] and Łukasz Rydzik [6,*]

[1] Faculty of Sport Sciences, Çanakkale Onsekiz Mart University, 17100 Çanakkale, Türkiye; kemal.kurak@comu.edu.tr
[2] Institute of Health Sciences, İnönü University, 44000 Malatya, Türkiye; isma_ilbak@hotmail.com
[3] Faculty of Sport and Physical Education, University of Nis, 18000 Nis, Serbia; stefan.stojanovicfsfv@gmail.com (S.S.); tijanapurenovic@gmail.com (T.P.-I.)
[4] Department of Physical Education and Sport Teaching, Malatya Turgut Ozal University, 44000 Malatya, Türkiye; ramazan.bayer@ozal.edu.tr
[5] Department of Physiology and Biochemistry, Faculty of Physical Education and Sport, University of Physical Education in Krakow, 31-571 Krakow, Poland
[6] Institute of Sports Sciences, University of Physical Education, 31-571 Krakow, Poland; tadek@ambrozy.pl
[7] Faculty of Medicine and Health Sciences, University Andrzej Frycz-Modrzejewski Krakow, 30-705 Krakow, Poland
[8] Institute of Physical Culture Studies, College of Medical Sciences, University of Rzeszow, 35-959 Rzeszow, Poland
* Correspondence: krzysztof.kasicki2@gmail.com (K.K.); lukasz.rydzik@awf.krakow.pl (Ł.R.)

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Abstract: The aim of this research was to investigate the effects of different stretching techniques used during warm-up exercises prior to post-activation performance enhancement (PAPE) on the explosive lower extremity strength performance of soccer players. This cross-sectional study involved the participation of 13 male soccer players with an average age of 22.38 ± 1.75, body height of 174.38 ± 3.94, and body mass of 72.30 ± 4.13. To determine the participants' maximal strength performance, one repeated maximal strength (1-RM) squat exercise was applied. The PAPE protocol was then implemented with a squat exercise consisting of three repetitions at 80% of 1-RM. The warm-up protocols consisted of 5 min of cycling, followed by dynamic stretching, static stretching, or proprioceptive neuromuscular facilitation (PNF) stretching exercises. These protocols were applied on four different days with a 72 h interval. A vertical jump test was conducted to measure the participants' explosive strength performance. The research data were analyzed using IBM Statistics (SPSS version 26.0, Armonk, NY, USA) software. The findings of this study revealed statistically significant differences in vertical jump performance values after PAPE among participants based on the different stretching techniques used during warm-up (p = 0.00). In this context, the research concluded that dynamic stretching is the optimal stretching technique during warm-up exercises before PAPE to maximize its effects. On the other hand, static stretching was found to negatively affect performance by absorbing the PAPE effect.

Keywords: PAPE; soccer; warm-up

1. Introduction

The utilization of various warm-up exercises for the acute enhancement of athletic performance is well established [1–3]. Particularly noteworthy in recent times are studies focusing on increasing key performance parameters through pre-loading with 75–90% of one repetition maximum (1-RM) [1,4,5]. In this context, the phenomenon known as post-activation performance enhancement (PAPE) is typically applied immediately after the warm-up phase and just before the execution of the fundamental performance task.

PAPE is defined physiologically as a voluntary muscle contraction resulting from the phosphorylation of the myosin light chain in type II muscle fibers [6]. Specifically, PAPE stimulates the flow of sarcoplasmic Ca^{2+} into the myoplasm by phosphorylating light chains and activating myosin light chain kinase. Consequently, this process supports the actin–myosin cross-bridge cycle due to increased Ca^{2+} sensitivity [7]. This may provide advantages for athletes in terms of performance output by making muscles more prepared for subsequent loads.

Additionally, an elevated intra-muscular temperature may play a significant role in this phenomenon [6]. While these factors seem to contribute to acute performance enhancement, there is still no conclusive evidence regarding the underlying mechanisms of PAPE. A review by Blazevich and Babault in 2019 [6] emphasized the lack of sufficient knowledge about the types of exercises that should be included in warm-up practices prior to studies investigating the effects of PAPE, suggesting that PAPE might be influenced by the techniques used in warm-up. Furthermore, studies in the literature have suggested that the effects of PAPE may diminish after a comprehensive warm-up [8,9]. Nevertheless, researchers [10–12] commonly opt for warm-up exercises comprising dynamic exercises following cycling as part of the warm-up routine before PAPE.

Ciocca et al. [10] conducted a study aiming to determine the temporal changes in PAPE levels. Prior to the PAPE protocol, they implemented 3 min of low-intensity running followed by 10 min of dynamic stretching exercises. Additionally, after these exercises, they conducted sprints of increasing intensity for 5 min, followed by gradually slowing down. The PAPE protocol was applied after a 2 min active rest period. In the research by Vargas-Molina et al. [11], which examined the effect of isometric and isotonic exercises before PAPE on vertical jump performance, they applied exercises including 5–7 min of steady cycling and dynamic joint mobilization. Subsequently, under the isotonic exercise, they applied loading consisting of two sets of three repetitions at 75% of 1-RM in the squat movement, with a knee flexion of 90° (referenced to full knee extension at 0°). For the isometric exercise, they applied loading involving a 4 s isometric contraction at knee flexion in the squat movement with an external load equivalent to 75% of 1-RM. After both protocols, a 4 min rest period was followed by the PAPE protocol. Krzysztofik et al. [7] investigated whether PAPE increased resistance volume during the Bench Press exercise. Their warm-up protocol included 5 min of cycling on a stationary ergometer (heart rate approximately 130 bpm), followed by 10 trunk rotations and side-bends on each side, 10 repetitions of internal and external rotary movements for the shoulders, and 10 push-ups. The rest interval for each participant was determined based on their intra-complex rest interval. In the study by Maroto-Izquierdo et al. [12], a 5 min cycling session was followed by a 5 min dynamic stretching protocol (e.g., forward leg swings, ankle dorsi- and plantarflexion, side leg swings, high knees, heel flicks, squats, and lunges) before PAPE. Guo et al. [13] aimed to investigate the post-activation performance enhancement in elite male sprinters with different power levels. Their study involved a 10 min warm-up protocol consisting of submaximal cycling followed by dynamic stretching and exercises involving vertical jumps after PAPE. Fu et al. [14] conducted a study to determine how PAPE affects explosive power performance in the lower extremities. Their warm-up protocol before PAPE included 10 min of cycling at a constant power (1 W per kg of body mass) and 5 min of dynamic stretching exercises (involving hips, knees, and ankles, as well as squats, jumps, and sprint movements) for a total of 15 min.

However, none of these studies have specifically focused on whether the stretching techniques used in the warm-up prior to PAPE affect post-PAPE athletic performance. Although warm-up exercises consisting of dynamic exercises following cycling are often preferred as pre-PAPE [15] warm-up protocols in the literature, there is a lack of standardization in terms of application methods and duration. Furthermore, how PAPE may be influenced by other stretching techniques used in warm-up is a subject of curiosity. In this context, a crucial question that remains to be addressed is what optimal warm-up exercises should be implemented before PAPE to maximize its effects.

Optimizing athlete performance through PAPE can provide significant advantages in competitions. Therefore, determining the optimal stretching technique applied during warm-up exercises before PAPE becomes crucial to induce the desired PAPE effects. In this context, the aim of this study was to examine the effects of different stretching techniques used during warm-up exercises preceding PAPE on athletes' explosive lower extremity strength performance. Considering the results of existing studies in the literature, the hypothesis of this research is that the most effective stretching technique applied during the warm-up phase is the dynamic stretching technique.

2. Materials and Methods

2.1. Participants

To determine the sample size for this study, G*Power 3.1.9.7 software (University of Düsseldorf, Düsseldorf, Germany) was utilized, employing the ANOVA repeated measures, within factors test for F-group tests. Effect size was determined with reference to the studies by Karampatsos et al. [16] and Silva et al. [17]. In this context, with an effect size of 0.392, a beta error probability (β) of 0.80, and an alpha error rate (α) of 0.05, it was determined that the participant group should consist of a minimum of 11 individuals. This study was conducted with the participation of at least 5-year licensed male soccer players (n = 13). The average characteristics of the participant group are presented in Table 1.

Table 1. Demographic and anthropometric information on participants.

Variables	*n*	Minimum	Maximum	Mean ± SD
Age (years)	13	20.00	25.00	22.38 ± 1.75
Body height (cm)	13	170.00	181.00	174.38 ± 3.94
Body mass (kg)	13	67.00	81.00	72.30 ± 4.13
1-RM performance (kg)	13	95.00	120.00	108.07 ± 7.51

2.2. Experimental Design

This cross-sectional study was conducted following the approval of the Ethics Committee of Inonu University Faculty of Health Sciences (approval no: 2024/5530) and in accordance with the Helsinki Declaration. In the study, a free-weight 1-RM squat protocol was applied to determine the lower extremity maximal force performance of participants. The PAPE protocol was implemented with a squat exercise involving three repetitions at 80% of 1-RM. The warm-up protocol included 4 different sessions conducted 72 h apart, consisting of 5 min of cycling, dynamic stretching exercises following 5 min of cycling, static stretching exercises following 5 min of cycling, and proprioceptive neuromuscular facilitation (PNF) stretching exercises following 5 min of cycling. All warm-up protocol sessions were administered to all participants in the same sequence. After each PAPE protocol, the participants were asked to rate their perceived difficulty ranging from 6 to 20 using the Borg Scale [18]) to determine their perceived difficulty during PAPE depending on the stretching techniques used in warm-up. Participants' explosive force performances were measured using a vertical jump performance test. Prior to data collection, introductory and trial sessions on warm-up procedures, vertical jump tests, and maximal squat force tests were conducted for each participant included in the research for two weeks. All intervention sessions took part at the same time of day. The PAPE protocol was applied approximately 3 min after the completion of warm-up procedures when the heart rate range was 110–120 bpm, and during this period, each member of the research groups was actively rested (walking). Participants were instructed to avoid engaging in different types of exercises the day before measurements, abstain from stimulating beverages such as tea, coffee, alcohol, and carbonated drinks, and eat their last meal at least 2 h before measurements. Figure 1 displays the experimental design diagram.

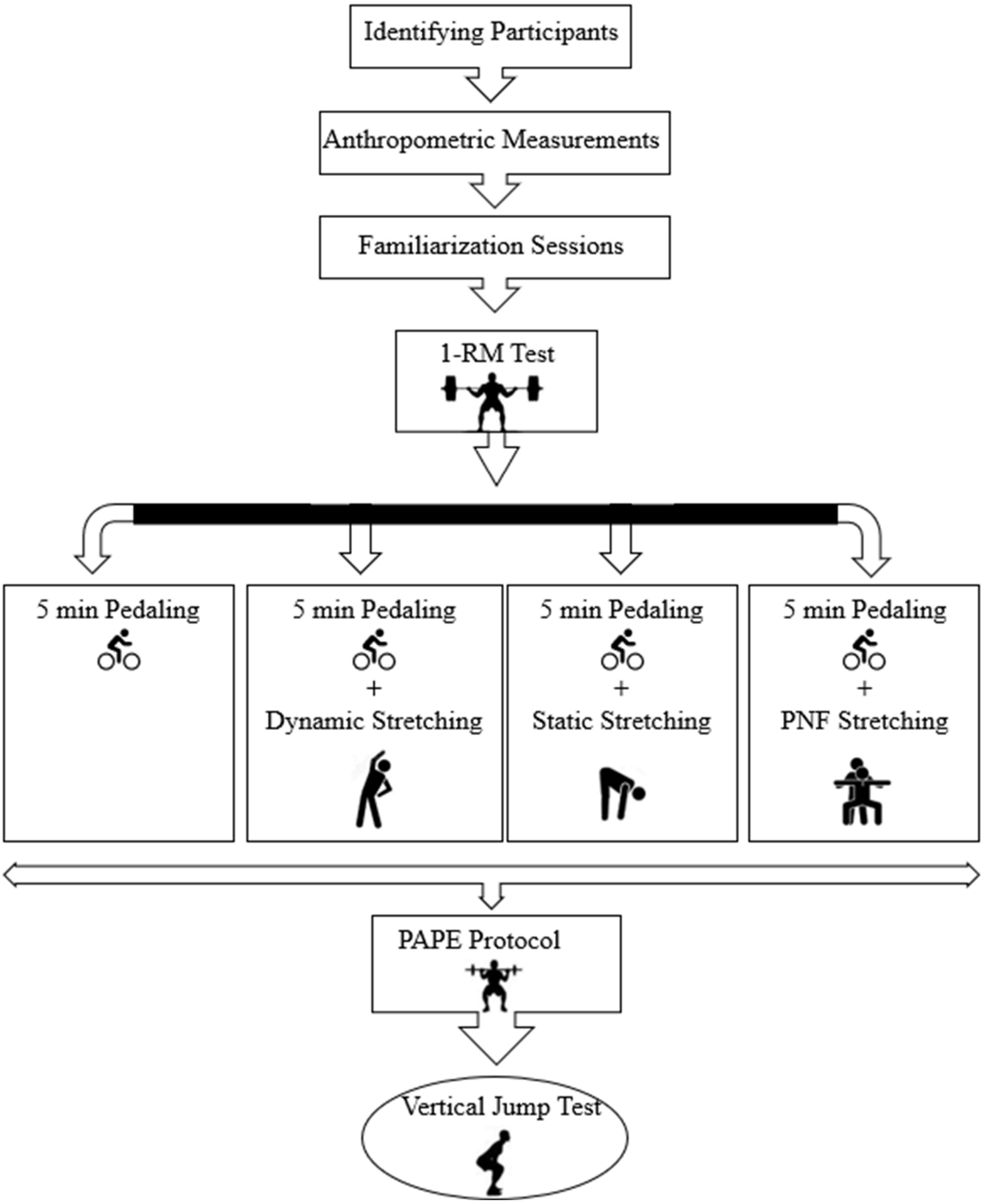

Figure 1. Experimental design diagram.

2.3. Anthropometric Measurements

All measurements of the participants in this study were conducted in accordance with the measurement techniques and standards recommended by the International Society for the Advancement of Kinanthropometry (ISAK) [19]. In this regard, heights were measured barefoot using a stadiometer (SECA, Hamburg, Germany) with a precision of 0.01 m, and body weights were measured in only shorts using an electronic scale (Tanita, SC-330, Tokyo, Japan) with a precision of 0.1 kg. Table 1 displays the results.

2.4. One Repetition Maximum Protocol (1-RM)

A 1-RM squat test was conducted to determine the 1-RM performance. Free weights and a barbell (Ohio Power Bar, Columbus, OH, USA) were utilized during the test. All participants determined their starting weights based on their preferences before commencing the full squat test. However, participants were advised to start the 1-RM test with approximately 30–40% of their body weight, following the guidelines proposed by Baechle and Earle [20]. During the test, participants were instructed to perform the movement, and additional weights of 2.5–5 kg were added based on the difficulty level they perceived (Borg Scale) to obtain strength values. The weight increment process continued until participants could no longer perform one repetition. The test was terminated when participants indicated they could not lift any more. In determining maximal strength, the rest period between sets ranged between 3 and 4 min. Participants commenced each set after declaring their readiness. All test results were recorded in kilograms.

2.5. Perceived Difficulty Level

The Borg Scale was employed to determine the perceived difficulty level. The Borg Scale is a valuable indicator for monitoring an individual's exercise tolerance, allowing participants to express the fatigue they feel during exercise on a scale ranging from nothing (6), very, very light (7–8), very light (9,13), light (11–12), somewhat hard (10,14), hard (15–16), very hard (17–18), very, very hard (19), to exhaustion (20). It can be particularly useful for tracking an individual's progression to maximal effort during exercise testing [18]. The Borg Scale was used during the participants' 1-RM performance tests to gauge perceived difficulty levels during weight loading. Additionally, following the application of the PAPE protocol after different stretching techniques, values were recorded using the Borg Scale to determine the participants' perceived difficulty levels. Table 2 displays the results.

Table 2. Perceived difficulty level after PAPE protocol based on the stretching technique used in warm-up.

Variables	*n*	Minimum	Maximum	Mean ± SD
5 min pedaling (a)	13	17.00	19.00	18.07 ± 0.954
5 min pedaling + Dynamic stretching (b)	13	14.00	16.00	15.23 ± 1.01
5 min pedaling + Static stretching (c)	13	18.00	20.00	19.00 ± 0.816
5 min pedaling + PNF stretching (d)	13	18.00	19.00	18.46 ± 0.518

2.6. Vertical Jump Test

The vertical jump test was conducted with an electronic mat vertical jump distance measuring device (Just Jump Technologies, Huntsville, AL, USA) [21]. Participants stood on the jumping mat with their feet shoulder-width apart and hands placed on the pelvis (crista iliaca). Participants were not allowed to take any steps before performing the vertical jump, but quarter squats were allowed before the jump [22]. During the test, participants were instructed to explosively jump using both feet simultaneously and land back on the mat. During the jump test, each participant was given one attempt. All participants were aware of this and participated in the test accordingly. The vertical jump mat measured the vertical jump height in centimeters based on the flight time, which is the time from when the feet leave the mat to landing.

2.7. PAPE Protocol

In the application of PAPE, the load intensity and number of repetitions per set were implemented taking into account the load intensities applied by Masel and Maciejczyk [23]. In this context, participants completed a set consisting of 3 repetitions with a 50% 1-RM load, followed by a recovery period of 180 s. Subsequently, after a recovery period of 180 s, participants performed another set with a 70% 1-RM load, again consisting of 3 repetitions. Finally, following another 180 s recovery, participants completed a set of 3 repetitions with an 80% 1-RM load. The vertical jump performance of the participants was measured after a recovery period of 180 s.

2.8. Warm-Up Protocols

2.8.1. Phase without Stretching

The protocol applied by Fu et al. [14] was implemented. In this context, a 10 min cycling session at a constant power (1 W per kilogram of participant's body mass) was performed before the PAPE. Additionally, a 5 min cycling session was conducted before all other stretching applications.

2.8.2. Dynamic Stretching

The protocol employed by Maroto-Izquierdo et al. [12] was applied. This involved 5 min of dynamic stretching exercises, including forward leg swings, ankle dorsiflexion and plantarflexion, side leg swings, high knees, heel kicks, squats, and forward lunges. Each exercise was performed for 20 s, and the entire set was repeated twice.

2.8.3. Static Stretching

Static stretching involves holding a joint in an extended position for 15 to 60 s at the end of the joint's range of motion [24]. Static stretching movements were applied for 30 s at the sensitivity threshold of pain [25]. For the abdominal muscles, participants engaged in "Russian Twists", while the pectoralis major muscle group was addressed with the "Wall Chest Stretch". Latissimus dorsi muscles were targeted through the "Wall Forward Bend" exercise. To address the hamstring region, individuals performed a stretching exercise by lying on their back and flexing the leg at the knee, pulling it towards the chest. For the quadriceps region, a prone position was adopted, and participants pulled the leg towards the buttocks by bending the knee. Lastly, the gastrocnemius region underwent stretching through the "Calf Raises" exercise.

2.8.4. Proprioceptive Neuromuscular Facilitation (PNF) Stretching

PNF is a widely employed stretching method that utilizes inhibition techniques, with muscle contract–relax and hold–relax being the most frequently used techniques. PNF stretching is typically performed with a 100% maximum voluntary isometric contraction [26], and applying this contraction for 3 to 10 s is recommended [26,27]. In this context, PNF stretching exercises were implemented, including the Russian Twist exercise for the right and left oblique muscles, the Wide Leg Seated Stretch exercise for the adductor region, the Supine Leg Pulling towards the Chest exercise for the hamstring region, the Prone Leg Pulling towards the Buttocks exercise for the quadriceps region, and the Calf Raises exercise for the gastrocnemius region. Each movement involved a 10 s cycle of muscle relaxation and contraction, with 2 sets performed for each exercise using the contract–relaxation and hold–relaxation techniques [28]. A 30 s rest period was provided between sets.

2.9. Data Analysis

Research data were analyzed using the IBM Statistics software package (version 26.0, Armonk, NY, USA). After testing the normality of the data using skewness and kurtosis values (within ±2), as recommended by Tabachnick and Fidell [29], Kim [30], and Mishra et al. [31], it was determined that the data exhibited a normal distribution. To identify differences between variables, a repeated measures ANOVA test was employed. Bonferroni post hoc tests were used to determine which variables contributed to the observed differences. To mitigate the risk of erroneously detecting significant effects across multiple comparisons, we employed the Bonferroni correction method to control the family-wise error rate (Type 1 error). The statistical significance level was set at $p < 0.05$.

3. Results

The analysis of Table 3 reveals a statistically significant difference in vertical jump performance values among participants after the post-activation potentiation exercise (PAPE) based on different stretching techniques used in warm-up ($p = 0.00$).

Table 3. Participant vertical jump performance values after PAPE for different stretching techniques used in warm-up.

Warm-Up Protocol	Mean ± SD	df	Mean Square	F	*p*
5 min pedaling	59.46 ± 2.817				
5 min pedaling + Dynamic stretching	61.38 ± 1.850				
5 min pedaling + Static stretching	58.15 ± 2.375	3	24.224	25.591	0.00
5 min pedaling + PNF stretching	60.30 ± 2.175				

According to the post hoc results, specific statistical differences between warm-up practices were determined as follows: in favor of dynamic stretching over 5 min pedaling ($p < 0.00$), in favor of 5 min pedaling over static stretching ($p < 0.01$), in favor of dynamic stretching over static stretching ($p = 0.00$), in favor of dynamic stretching over PNF stretching ($p < 0.01$), and in favor of PNF stretching over static stretching ($p = 0.00$). In this context, the most effective warm-up protocol for inducing the PAPE effect is the dynamic stretching protocol. The least efficient warm-up protocol for inducing the PAPE effect is the static stretching protocol. Furthermore, the solely 5 min pedaling and PNF protocols can be considered as alternatives to each other. Moreover, both of these protocols are inefficient compared to the dynamic stretching protocol and more efficient than the static stretching protocol.

The perceived difficulty levels after the PAPE protocol, based on the stretching technique used in the warm-up, were observed to have the highest to lowest averages in the following order: static stretching (very, very difficult), PNF stretching (very difficult), 5 min pedaling (very difficult), and dynamic stretching (difficult).

4. Discussion

The aim of this study was to examine the effects of different stretching techniques used during warm-up exercises preceding PAPE on athletes' lower extremity explosive force performance. The research findings indicate a statistically significant difference in vertical jump performance values after PAPE for different stretching techniques used in warm-up. Specifically, to increase the effects of PAPE on lower extremity power performance, dynamic stretching was found to be more favorable than 5 min pedaling, 5 min pedaling was more favorable than static stretching, dynamic stretching was more favorable than static stretching, dynamic stretching was more favorable than PNF stretching, and PNF stretching was more favorable than static stretching. Additionally, the variation in perceived levels of difficulty following PAPE depending on the stretching technique applied is noteworthy. Considering the average scores obtained from the scale, it is intriguing that the highest perception of difficulty is reported after static stretching, while the lowest perception of difficulty is reported after dynamic stretching. Based on these findings, it can be said that, to maximize the effects of PAPE, the optimal stretching technique during warm-up exercises preceding PAPE is dynamic stretching, while static stretching may absorb the effects of PAPE and negatively impact performance.

The results we reached are not surprising, given that there are a number of studies that have found an improvement in match performance by using a dynamic warm-up before competition [32–35]. Moreover, this confirms the hypothesis of this study, which asserts that the most effective stretching technique to trigger the PAPE effect on the lower extremities is the dynamic stretching technique. In this regard, our results are in accordance with the results of the previously mentioned studies, which also used dynamic stretching of several muscle groups. Another advantage of dynamic over static stretching is that it implies a greater increase in heart rate compared to static stretching, and it has already been proven that dynamic stretching at fast speeds is good for muscle performance improvement in contrast to low speeds due to increments in heart rate [36]. The increased heart rate, improved blood circulation, and enhanced synergy, reflex speed, and adrenaline secretion during high-speed dynamic stretching may contribute to enhanced performance. This could potentially allow for greater oxygen transportation, increased coordination, and elevated energy levels. Many studies have investigated the effects of various types and durations of stretching. The outcomes of this research can be classified as acute or training effects. Acute effects measure the immediate effects of stretching, whereas training effects examine the effects of stretching over time. Stretching studies also vary in terms of the muscles or muscle groups being investigated, as well as the populations studied, making interpretation and recommendations challenging and relative. Each of these elements must be addressed when drawing conclusions from research investigations, but there are few systematic reviews with broad recommendations [37–39]. Good range of motion (ROM), or flexibility around a joint, is vital for performance and motor tasks since it allows for a full functional range. There is also evidence that poor flexibility [40] and increased stiffness of muscle tendons [41] are related to a higher risk of muscle damage. This occurs because demands for energy absorption and release might quickly surpass the muscle tendon unit's stiffness capacity [42]. Normally, flexibility affects the sports performance of athletes [43]. In addition, static stretching [44] and PNF stretching [45] are stretching strategies that have been shown to be successful in acutely increasing athletic performance. The results of our study are also in line with previous literature regarding static and PNF stretching. However, as shown in Table 4, a greater effect on lower-limb power output was caused by dynamic stretching. There is a study [46] that shows that static stretching has a negative effect on explosive power, while dynamic stretching increases explosive power. Considering that our results showed that dynamic stretching was favorable compared to static stretching, but that both types of stretching led to improvement, we can say that the results were not in accordance with the mentioned study. It must be taken into account that [46] did not apply PAPE, but only compared the effects between the mentioned stretching techniques on vertical jump performance. In addition, a large number of studies have compared the impact of static and dynamic stretching on performance indicators such as jump tests, etc., and it has been observed that dynamic stretching has a positive effect [47], while static stretching has a negative effect [48]. Given the existing literature that indicates improvements in muscle performance with the application of dynamic stretching, we suggest that dynamic stretching prior to the PAPE protocol can increase the explosive power of athletes, in this case soccer players.

Table 4. Post hoc test results.

Variables	5 min Pedaling	5 min Pedaling + Dynamic stretching	5 min Pedaling + Static stretching	5 min Pedaling + PNF stretching
5 min pedaling	-	$p = 0.00$	$p < 0.01$	$p > 0.05$
5 min pedaling + Dynamic stretching	$p = 0.00$	-	$p = 0.00$	$p < 0.01$
5 min pedaling + Static stretching	$p < 0.01$	$p = 0.00$	-	$p = 0.00$
5 min pedaling + PNF stretching	$p > 0.05$	$p < 0.01$	$p = 0.00$	-

The findings and implications obtained in this study have been presented within the limitations of the research. In order to guide future research, various limitations of this study are detailed. In this context, the limitations of this research are as follows: the application of only the squat exercise to create the PAPE effect in the lower extremities, the loading intensity for creating the PAPE effect being set at 80% of 1-RM, measurement of vertical jump performance 180 s after the PAPE application, and the research group consisting exclusively of male soccer players. Additionally, all warm-up protocol sessions were applied to all participants in the same sequence. Since we could not determine whether the vertical jump performance of athletes was affected by this sequence, this is also one of the significant limitations of this study.

5. Conclusions

The results of this study indicate that PAPE may be influenced by stretching techniques applied during warm-up. Particularly, the finding that exercise practices involving dynamic stretching techniques applied during warm-up have a positive impact on PAPE is noteworthy. On the other hand, it was determined that exercise practices involving static stretching techniques applied during warm-up have a negative effect on PAPE. There was no statistically significant difference observed between PNF stretching and the exercise without stretching (only pedaling), and no adverse effect on PAPE was observed. In this context, researchers and athletes are recommended to incorporate exercises containing dynamic stretching techniques before PAPE.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in this study.

Data Availability Statement: The data presented in this study are available from the corresponding author upon request due to privacy issues.

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