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Review

The Impact of Post-Activation Performance Enhancement Protocols on Vertical Jumps: Systematic Review

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Abstract: Background: The post-activation performance enhancement (PAPE) protocol is frequently utilized to enhance athletic performance through high-intensity stimuli. Despite its popularity, the effectiveness and mechanisms of PAPE remain unclear, particularly in the context of improving jump performance in sports. **Methods:** A systematic review was conducted following the PRISMA guidelines. A comprehensive search was conducted across databases including Scopus, Web of Science, PubMed, and EBSCO up to 31 March 2024. **Results:** Initially, 481 studies were identified, of which 8 were finally included, involving a varied number of participants, each focusing on the impact of PAPE on jump performance. These studies predominantly indicated that PAPE protocols can lead to short-term improvements in jump performance. Two publications demonstrated a positive effect on jump height, and one of them reported a questionable effect on jump height in the initial time period, while the remaining five publications showed a positive impact on jump performance. The average increase in height achieved based on the intervention from the publications was 4.03% ($p < 0.05$). Variability in effectiveness was noted depending on the type of exercises used in the activation phase, timing of performance post activation, and individual physiological characteristics. **Conclusions:** PAPE protocols can effectively enhance jump performance in athletic populations, although outcomes vary based on protocol specifics and individual differences. These findings support the need for individualized approaches in the application of PAPE protocols to optimize athletic performance.

Keywords: PAPE; jump performance; athletic enhancement; sport-specific training

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1. Introduction

Modern sports challenge athletes to maximize their physical performance, requiring the use of advanced training methods. Recently, a comprehensive method known as contrast training has gained popularity. It involves the application of intense stimuli to temporarily enhance neuromuscular system performance. This method utilizes the phenomenon of post-activation potentiation (PAP), resulting in a momentary increase in motor abilities, termed post-activation performance enhancement (PAPE) [1]. PAP and PAPE differ in terms of mechanisms, range of effects, and practical application. PAP focuses on neuromuscular improvement in function following intense effort, whereas PAPE encompasses a broader context of performance enhancement in sports [1]. Despite widespread use in sports practice, the effectiveness and mechanisms of post-activation performance enhancement, especially regarding long-term improvements in explosive strength and the efficacy of different protocols, remain not fully elucidated. Recent studies by Casais Barreto et al. and Rumeau et al. [2] have provided insights into the role of PAPE in various sports disciplines, highlighting the need for further investigation into protocol-specific outcomes. PAPE is based on the premise that performing a brief, intense effort before a sports task can

enhance physical performance through changes in neuromuscular system activity. These changes include recruitment of more motor units, improved coordination within muscles (synchronization of agonist muscles), and intramuscular coordination (synchronization of motor units) [3–5] as well as alterations in muscle metabolism induced by factors such as local muscle temperature increases or shifts in tissue fluids, which alter muscle contraction mechanics [1]. Contemporary research on enhancing athletic performance increasingly focuses on the use of advanced training methods, such as [6]. PAPE protocols are employed to achieve short-term improvements in motor abilities by applying intense stimuli before the main sports task. The mechanism of PAPE operates by enhancing neuromuscular function, including the recruitment of a greater number of motor units and the improvement of intramuscular coordination [1].

Despite the growing popularity of PAPE, few systematic reviews have focused exclusively on its impact on vertical jumps among athletes. Previous reviews have examined similar concepts, such as in the context of various performance indicators (e.g., Seitz and Haff, 2016; Wilson et al., 2013) [7,8]. However, a comprehensive systematic review that analyzes the diversity of PAPE protocols and their specific application in improving vertical jump performance remains unrealized. Our study aims to fill this gap by analyzing existing research on the effectiveness of various PAPE protocols.

Despite understanding the fundamentals of this phenomenon, there is considerable variability in the research findings regarding the effectiveness of PAPE protocols. Some studies have suggested that these protocols can lead to short-term increases in muscle power production capacity, as evidenced by improvements in jump height or distance following activation stimuli [9]. For instance, Berriel et al. found positive effects on jump heights among professional volleyball players using a plyometric-based protocol [10].

Simultaneously, publications exist whose results indicate either no significant or a negligible impact of the PAP effect on motor performance expression [11–13]. Vargas-Molina et al. demonstrated that despite using loads at 75% of one-repetition maximum in isotonic and isometric exercises as a PAPE-enhancing protocol, there were no significant improvements in countermovement jump (CMJ) height [11].

Thus, the efficacy of applied protocols appears variable and may depend on factors such as the types of exercises used (both main and activation exercises) [7,8,14], execution methods (e.g., range of motion and stretch-shortening cycle time) [15–18], intensity, rest periods (between activation stimulus and main exercise) [19], and the individual morphological and physiological characteristics of the study group [20].

The aim of this systematic review is to analyze current research on the effectiveness of PAPE protocols in improving vertical jump performance across different types of jumps [21]. The conclusions drawn from this review will address whether and which PAPE protocols are worth applying in practical training settings. This systematic review seeks to answer the following research questions: (1) Do different PAPE protocols yield varying effects on jump performance? (2) What are the key factors influencing the effectiveness of PAPE in different athletic populations?

2. Materials and Methods

2.1. Study Design

A systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

2.2. Literature Search

Electronic searches were conducted in the following databases without time restrictions: Scopus, Web of Science, PubMed, and EBSCO. Studies were considered from their inception dates up to 31 March 2024. The following search formulas were applied to the respective databases:

1. Scopus: TITLE-ABS-KEY((pape OR “Post activation performance enhancement”) AND (“vertical jump” OR “jump performance” OR jump))

2. PubMed: ("pape"[Title/Abstract] OR "Post activation performance enhancement" [Title/Abstract]) AND ("vertical jump"[Title/Abstract] OR "jump performance"[Title/Abstract] OR "jump"[Title/Abstract])
3. EBSCO: (pape OR "Post activation performance enhancement") AND ("vertical jump" OR "jump performance" OR jump)
4. Web of Science: (AB = ((pape OR "Post activation performance enhancement") AND ("vertical jump" OR "jump performance" OR jump))) OR TI = ((pape OR "Post activation performance enhancement") AND ("vertical jump" OR "jump performance" OR jump))

The gathered studies were evaluated for errors and duplicates and confirmed based on title, abstract, and full-text screening.

2.3. Inclusion and Exclusion Criteria

The studies included in the review were selected according to the following PICO(s) criteria, with a focus on ensuring methodological rigor. Articles were excluded if they lacked full-text availability, were not published in peer-reviewed journals, or if the study design did not include a control group. Additionally, non-English language studies and those with sample sizes below 10 participants were excluded to minimize bias (Ł.R. conducted the process of establishing the following criteria). Detailed criteria are presented in Table 1.

Table 1. Inclusion and Exclusion criteria.

Category	Inclusion Criteria	Exclusion Criteria
Population	Participants aged 18 and older, with a minimum of two years of experience in strength training or their respective sport, and without any health issues were included in the study.	Participants under the age of 18, without any experience in any form of training, and classified as recreational exercisers with health issues were excluded from the study.
Intervention	A defined PAPE protocol: Taking into account the use of 70% of the maximum weight or more in the applied method or variations of exercises related to vertical jump.	Lack of a strictly defined PAPE protocol: Lack of monitoring the load relative to the maximum weight and lack of specified numbers of sets or repetitions.
Comparator	Participants engaged in standard training programs specific to their training regimen.	Absence of control group.
Outcome	At least one measurement assessing vertical jump performance related to sport-specific outcomes before and after the intervention.	Lack of baseline data.
Study design	Experimental design with a control group.	Cross-sectional studies.

2.4. Selection Process

The collected data were evaluated by both authors (M.S. and T.A) as independent reviewers. In cases of disputes regarding the criteria required for a publication, a joint consolidation and discussion took place to determine the validity of including the publication in the review. To minimize bias as much as possible, the search results were evaluated by other authors. In cases where consensus could not be reached, discussions were held with the remaining authors to establish a unified stance on the inclusion of a particular article in the review.

2.5. Data Collection Process

In a total of three stages, two authors individually worked on the screening process (K.K. and P.K.). In stages 1 and 2, they worked separately on their own individual databases, which were created using the same search terms for each scientific database. In stage 3, the collected data were evaluated by both authors (Ł.R. and T.A.) as independent reviewers. In cases of disputes regarding the criteria required for a publication, a joint consolidation and discussion took place to determine the validity of including the publication in the review.

2.6. Data Items

In this systematic review, we extracted various data items to assess the effectiveness of the post-activation performance enhancement (PAPE) protocols on vertical jump performance. The following data items were collected:

- Participant Characteristics: Age, gender, training background (e.g., years of experience in strength or sport-specific training), and the specific sport in which the participants were involved;
- Study Design: Type of study (e.g., randomized controlled trial, crossover study, etc.), sample size, and the presence of control or comparison groups;
- PAPE Protocols: Detailed description of the PAPE protocols used, including the type of exercises, intensity (e.g., percentage of one-repetition maximum), number of sets and repetitions, and rest intervals;
- Outcome Measures: Specific outcomes related to vertical jump performance, such as jump height, peak power, and other relevant measures of pre- and post-intervention athletic performance.
- Timing of Measurements: The specific time points at which performance outcomes were measured following the PAPE protocol (e.g., immediately after, 3 min, 9 min, etc.);
- Adverse Effects: Any reported negative effects or injuries resulting from the PAPE protocols.

These data items were systematically extracted and analyzed to determine the overall effectiveness and variability in the outcomes of PAPE protocols across different studies.

2.7. Effect Measures

The primary effect measure used in this systematic review was the change in vertical jump performance (e.g., jump height) following the application of PAPE protocols. The effectiveness of PAPE was primarily quantified by comparing pre- and post-intervention performance metrics within the same group and between experimental and control groups where applicable. The magnitude of performance enhancement was typically expressed as a percentage increase in jump height or peak power output, with statistical significance being evaluated using p-values (e.g., $p < 0.05$). Additionally, effect sizes were calculated where possible to provide a standardized measure of the impact of the PAPE protocols across different studies.

These effect measures were critical in determining the overall efficacy of PAPE protocols and in understanding the factors that contribute to variability in performance outcomes among different athletic populations.

2.8. Assessment of Study Quality

The PEDro scale was employed to evaluate the methodological quality of the studies. This scale consists of 11 criteria, including eligibility; randomization; allocation concealment; baseline comparability; blinding of participants, therapists, and assessors; follow-up completion of at least 85%; intention-to-treat analysis; between group statistical comparisons; and reporting of point estimates with variability. The first criterion is related to external validity and is not included in the final score. Each of the remaining items can score 1 or 0 points, with a maximum score of 10. Studies scoring 6 or above were considered to be of high quality [22]. None of the evaluations were extracted directly from the PEDro database. All assessments were conducted manually, following the criteria outlined in the PEDro scale.

3. Results

3.1. Literature Search Results

After searching databases using the specified keywords, initially, 481 scientific articles were identified. After excluding 348 articles due to duplicates, lack of full access, absence of full text, or non-English text, 133 articles remained. These were screened based on their

titles and abstracts, resulting in the selection of 31 publications that were thoroughly read to assess their compliance with inclusion and exclusion criteria. An outline of the search strategy is depicted in Figure 1.

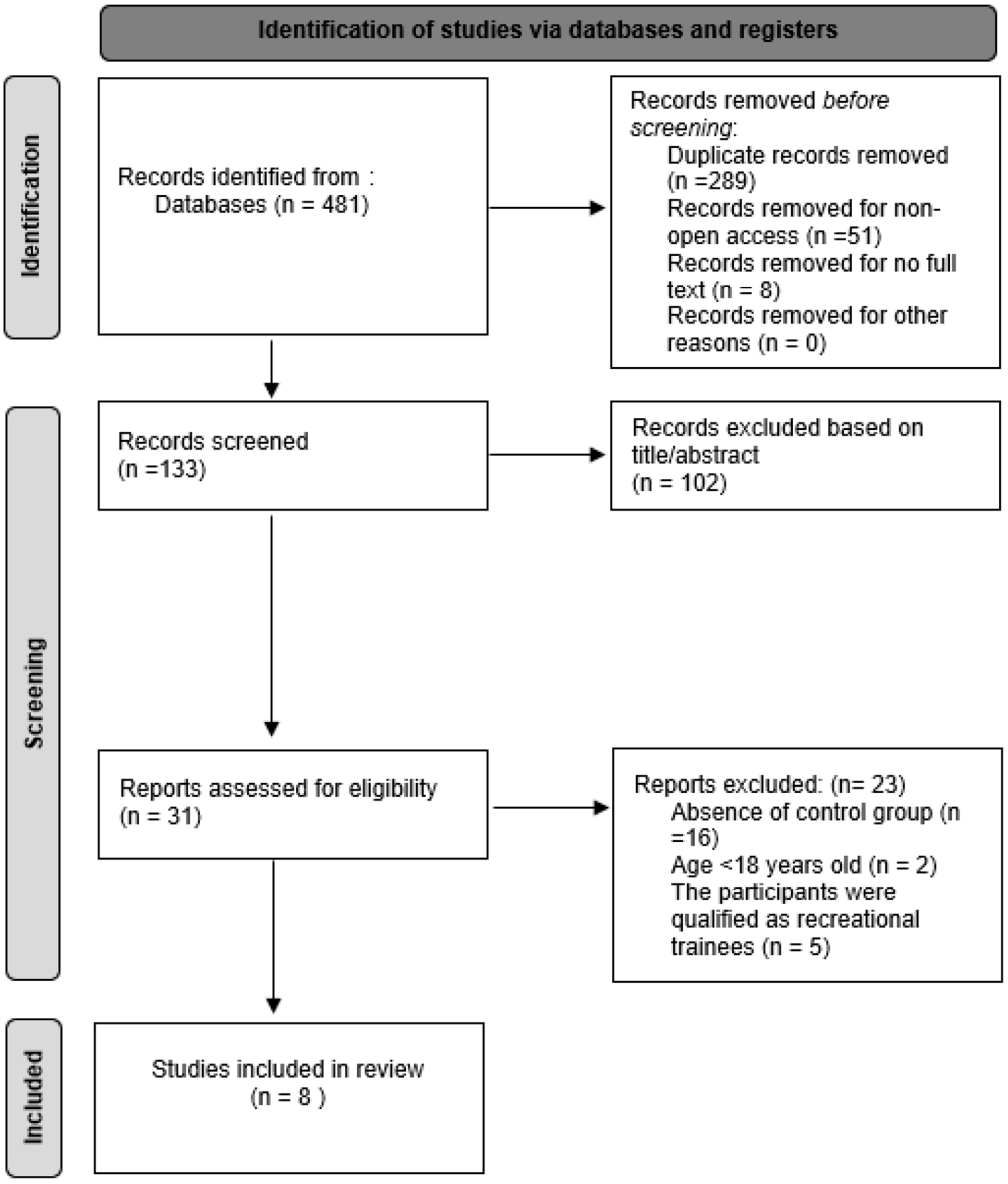


Figure 1. PRISMA flowchart for identification and selection of study in review.

3.2. Study Characteristics

Detailed descriptions of the included studies are provided in the table below, including division into experimental and control groups, the PAPE protocol used, and the results and conclusions of the authors. Eight studies were included (where each of them is a comparative study, five of them are randomized controlled trials [10,12,23–25]), of which three focused on 40 volleyball players [10,12,26], three on 127 individuals with significant experience in strength training [24,25,27], one on 26 basketball players [23], and one on 31 handball players [28]. The total number of participants included in the studies was 224 individuals aged 18 and above. The experimental groups comprised a total of 115 (+31) participants, while the control groups comprised 78 (+31) participants. Only two experimental and control groups consisted exclusively of women [26,27]; the rest involved men. Among the four qualifying studies, the PAPE activation protocol utilized submaximal loads (>70%) in four cases [10,12,24,26], while isometric methods and

loads below 50% of maximal weight were used in the remaining studies [23,26,28,29]. The average increase in height achieved based on the intervention from the publications was 4.03% ($p < 0.05$). Detailed results and key information regarding the studies included in the systematic review are presented in Table 2.

Table 2. Characteristics and results of studies included in systematic review.

Lp.	Authors and Type of Article	Experimental Group	Control Group	PAPE Effect Protocol	Results	Conclusions
1	Biel P. et al. (2023) [23]	13 male subjects Average age: 24 ± 6 Athletes playing basketball at a semi-professional level for at least six years.	13 male subjects	Participants performed a conditioning activity (CA) consisting of 3 sets of 5 DJ with a 60-s rest between each set. DJ were executed from a 60-cm wooden box.	The authors did not find statistically significant interactions for jump height, peak relative power, and depth of movement in the CMJ.	None of the training methods used had a significant impact on the PAPE response.
2	Villalon-Gasch L et al. (2022) [26]	6 female subjects Average age: 21.33 ± 3.0 Athletes with four years of minimum experience in volleyball training, playing in Superliga 2.	6 female subjects	An activation protocol was conducted, consisting of an initial phase (12 repetitions at 20 kg, 3-min rest, followed by 5 repetitions at 50% of 1RM and another 3-min rest), followed by a main phase (3 repetitions in half-squat at 90% of 1RM).	The authors observed an improvement in jump performance during a volleyball match. They noted an increase in CMJ height in the experimental group.	The application of the selected activation protocol by the authors, consisting of 3 repetitions at 90% of 1RM in the half-squat exercise, induced the PAPE effect and generated a difference in increasing CMJ height.
3	Koźlenia D. and Domaradzki J. (2024) [24]	22 male subjects Average age: 21.5 ± 2.3 Participants with experience in strength training of at least 6 years and in continuous resistance training for at least 2 years.	23 male subjects	The protocol involved 3 sets of isometric effort in the full squat position with a barbell on the back, lasting 4 s each at 70% of one-repetition maximum (1RM), with 60-s rest intervals between sets.	The authors demonstrated significant differences between the initial measurements of jump height (JH) and all measurements taken after the activation protocols were applied.	The protocol used by the authors in the study positively impacted the induction of the PAPE effect, consequently leading to an improvement in performance JH.
4	Berriel G.P. et al. (2022) [10]	8 male subjects Average age: 26.8 ± 6.1 Players of a high-performance volleyball team from Brazil; athletes with at least two years of experience in national and international competitions.	8 male subjects	Three sets of hack squats were performed with a load equivalent to a 3-repetition maximum for each participant in the study.	The results presented by the authors of the study indicate significant differences between the groups after the training session, specifically following the introduction of the activation protocol. They observed a significant increase in CMJ performance compared to baseline values	The study demonstrated a positive effect on jump performance following the induction of the PAPE protocol proposed by the authors.
5	Spieszny M. et al. (2022) [28]	Male subjects (31 overall) Average age: 19 ± 2 Athletes with at least four years of training and competition experience.	Male subjects (31 overall)	Participants warmed up with 5 min of cycling and body-weight exercises. After a 5-min rest, they performed three sets of three 3-s maximal isometric rear squats at 90 degrees, with 3 min of rest between sets.	The heights of SJ CMJ were significantly higher at peak times compared to baseline values in both experimental and control conditions, with a greater increase observed in the experimental conditions.	The proposed protocol demonstrated a positive effect on the performance improvement of CMJ and SJ in the short term.

Table 2. *Cont.*

Lp.	Authors and Type of Article	Experimental Group	Control Group	PAPE Effect Protocol	Results	Conclusions
6	Masel S. and Maciejczyk M. (2022) [12]	6 male subjects Average age: 23 ± 2 Athletes competing in the second-highest volleyball division in Poland.	6 male subjects	After 180 s of rest, participants in the experimental group performed 3 repetitions of the trap bar deadlift at 80% of their 1RM, followed by a 90-s rest period.	According to the analysis conducted by the authors, no significant differences were observed in CMJ and SJ parameters following the application of the PAPE induction protocol.	The activation protocol proposed by the authors did not induce a PAPE effect in CMJ and SJ jump tests.
7	Koźlenia, D. and Domaradzki, J. (2023) [27]	29 female subjects EXL: 15 VE: 14 Age: 19–23 years old Athletes with at least six years of experience in strength training.	12 female subjects	The EXL group did three sets of 4-s isometric back squats at 70% of 1RM, while the VE group did three sets of 5-second maximal isometric contractions against an immovable beam, with one-minute rest intervals.	The analysis revealed significant improvements in jump performance for the EXL and VE groups compared to the control group, which saw minimal changes. The EXL group showed better performance at 3 min, while the VE group peaked at 9 min. The JH group experienced declines in performance at 3, 5, and 7 min.	Both PAPE protocols proposed by the authors improved jump performance among the study participants in the experimental groups.
8	Koźlenia, D. and Domaradzki, J. (2023) [25]	31 male subjects ST-ISO: 17 ISO: 14 Age: 18–24 years old Participants with experience in strength training of at least 6 years and at least 3 years in continuous resistance training.	10 male subjects	The ST-ISO group performed three sets of five-second maximal isometric contractions against an immovable beam, followed by two sets of full-range squats at a 5-0-5-0 tempo with a metronome and took two-minute breaks between sets. The ISO group only did three five-second pushes against the beam with one-minute breaks.	The analysis confirmed positive PAPE effects compared to the control group. In the ISO group, significant differences were noted at the 5th and 9th minutes. In the ST-ISO group, CMJ height decreased at the 3rd and 7th minutes, peaking at the 9th. Chi-square analysis showed a significant relationship between time and performance.	The authors observed varying effects of the activation protocols. Both initially led to a performance decrease, particularly in the ST-ISO group. However, performance improved in the later minutes, peaking during the final measurement. Overall, both protocols cumulatively enhanced jump performance, with the ST-ISO group showing better results.

CA, conditioning activity; CMJ, countermovement jump; 1RM, one repetition maximum; SJ, squat jump; JH, jump height; DJ, depth jump; PAPE, post-activation performance enhancement.

Of the studies analyzed, two demonstrated high quality, while the remaining six showed moderate risk (Table 3).

Table 3. PEDro scale for the included studies.

Reference	1	2	3	4	5	6	7	8	9	10
1. Biel P. et al. (2023) [23]	+	-	+	-	-	-	+	-	+	+
2. Villalon-Gasch L et al. (2022) [26]	+	+	+	-	-	-	+	-	+	+
3. Koźlenia D. and DomaradzkiDomara-dzki J. (2024) [24]	+	-	+	-	-	-	+	-	+	+
4. Berriel G.P. et al. (2022) [10]	+	+	+	-	-	-	+	-	+	+
5. Spieszny M. et al. (2022) [28]	+	-	+	-	-	-	+	-	+	+
6. Masel S. and Maciejczyk M. (2022) [12]	+	-	+	-	-	-	+	-	+	+
7. Koźlenia, D. and DomaradzkiDo-maradzki, J. (2023) [27]	+	-	+	-	-	-	+	-	+	+
8. Koźlenia, D. and DomaradzkiDo-maradzki, J. (2023) [25]	+	-	+	-	-	-	+	-	+	+

Pedro items: 1. Randomization; 2. Allocation concealment; 3. Comparability at baseline; 4. Patient blinding; 5. Therapist blinding; 6. Assessor blinding; 7. At least 85% follow-up; 8. Intention to treat analysis; 9. Between-group statistical comparisons; 10. Point measures and measures of variability. Marks: (+), item fulfilled; (-), item not fulfilled.

3.3. Main Outcomes

The systematic review explored the effects of PAPE protocols on vertical jump performance, drawing on data from eight studies with a total of 224 participants. The key findings demonstrate that PAPE protocols can lead to short-term improvements in jump performance, although the magnitude of these improvements varies depending on the specifics of the protocol and the characteristics of the participants.

Most studies reported significant increases in jump height following the application of PAPE protocols. For instance, a study on elite female volleyball players observed improvements in countermovement jump height after using a protocol involving half-squat exercises at 90% of one-repetition maximum (1RM). Similar positive effects were noted in high-level volleyball players who experienced enhanced CMJ performance after performing hack squats with heavy loads. These results suggest that high-intensity exercises targeting major muscle groups involved in jumping can effectively induce the PAPE effect.

However, not all studies found significant effects. For example, a study on semi-professional basketball players reported no substantial changes in jump height, peak relative power, or movement depth following PAPE interventions. This variability in outcomes indicates that the effectiveness of PAPE is influenced by factors such as the type of activation exercises used, the timing of post-activation performance, and individual physiological differences among athletes.

Furthermore, protocols using isometric exercises also showed promise. Studies demonstrated that isometric squats could effectively enhance jump performance, highlighting that different types of muscle contractions might be useful for inducing the PAPE effect.

In conclusion, while PAPE protocols generally enhance vertical jump performance, their effectiveness can be highly individualized. These findings underscore the importance of tailoring PAPE protocols to the specific needs and characteristics of athletes to maximize performance improvements. Future research should aim to refine these protocols, considering variables such as load intensity, type of exercise, and recovery periods to optimize the application of PAPE in athletic training.

4. Discussion

The use of the protocol is widespread in the scientific community, as evidenced by numerous scientific publications [14,29–31]. However, only a small portion of these studies are supported by properly designed experiments that include a control group [10,12,23–28]. The PAPE effect refers to the short-term improvement in athletic performance following a high-intensity training stimulus [32]. In the analyzed study, both complex potentiation exercises (CPX) and complex movement potentiation (CMP) were used to induce PAPE, but the results did not show significant differences between these two methods in terms of their effectiveness in inducing this effect [23]. These findings are significant because they suggest that despite differences in training structure, both methods are equally effective in eliciting short-term performance improvements. This can be crucial for coaches and athletes in planning training sessions, especially in sports where brief moments of effort determine performance outcomes, such as basketball [33]. The application of CPX or CMP can be effective in enhancing specific skills like jumps or sprints through strategic planning and the use of weights and exercises that induce PAPE before main training components or competitions [23]. It is also worth noting that the lack of significant differences in PAPE induction between CPX and CMP raises questions about other factors, such as individual physiological characteristics of athletes, types of exercises, exercise intensity, or recovery time between exercises, that may influence PAPE effectiveness.

Protocols PAPE is associated with various physiological processes, such as muscle temperature increase, muscle water content change, or activation of a greater number of motor units [7,26]. This distinction is important because it allows for a better understanding and optimization of training protocols. Additionally, the study showed that PAPE effects depend on many individual factors, such as physiological characteristics of athletes, their experience, age, distribution of muscle fibers, and training level [26]. This means that PAPE

effectiveness may vary depending on individual athlete characteristics, suggesting the need for customization of activation protocols.

In the study "Postsubmaximal Isometric Full Squat Jump Potentiation in Trained Men", an attempt was made to examine the impact of submaximal isometric squats on jump height in a group of trained men. Participants were divided into an experimental and control group, where the experimental group performed isometric squats with a load of 70% of one-repetition maximum (1RM) [25]. The results showed that as early as the third minute after the conditioning activity (CA), there was a statistically significant improvement in jump height, which persisted for the next 6 min [24]. These findings are important for understanding the mechanisms behind and may have significant practical implications.

PAPE, as a phenomenon involving short-term performance improvement after conditioning activity, is traditionally used in various sports disciplines, but research on isometric muscle actions as a form of activation has been less widespread. This study underscores that full isometric squats can be an effective tool for improving jump performance, which can be valuable in sports where such abilities are crucial [28]. Moreover, this study adds significant information to the literature regarding the optimal timing of PAPE, suggesting that the best effects occur between 3 and 9 min after CA [28]. Another significant aspect is the use of submaximal loads, which, as the results indicate, can effectively induce PAPE without excessive fatigue, which is critical for athletes interested in maximizing performance without risking injury or excessive strain [34]. These findings can be used to optimize training, especially in the context of competition preparation, where precise timing and type of activation can significantly enhance athletic performance [34].

The study by Berriel and colleagues on the impact of post-activation performance enhancement on countermovement jump height among professional volleyball players observed that PAPE intervention led to a significant increase in CMJ height by 16.3%, while the control group without PAPE intervention experienced a decrease of 5% [10]. These results are crucial for understanding how muscle activation before proper training can significantly impact athletic performance. PAPE, known for the short-term increase in muscle strength after prior conditioning activity, was applied in this case through plyometric exercises with additional resistance. Importantly, there were no differences between groups in perceived recovery scores (PRS) or effort ratings (RPE), indicating that despite increased training load, the perception of effort and recovery remained unchanged [10]. Such findings have significant implications for coaches and athletes, suggesting that appropriately planned PAPE interventions can improve key athletic skills like jumps without causing additional perceptual fatigue [17]. Furthermore, this points to the possibility of integrating such training strategies into routine athlete preparations to maximize their performance during competitions [35].

The study demonstrated that both SJ and CMJ jumps showed significant increases in height after CA. Interestingly, both displacement jumps, which involve a stretch–shortening cycle (SSC), and non-displacement jumps showed similar responses to PAPE. It is worth noting that the presence or absence of SSC in the CA action and subsequent tasks did not significantly influence the PAPE response, which may suggest that potentiation mechanisms operate similarly regardless of the nature of the movement task [27]. Some studies have suggested that similarity in movement range and type of contraction between CA and subsequent tasks may enhance the PAPE effect. However, the results of this study do not confirm this hypothesis, as improvement occurred independently of SSC utilization [27]. Such findings may lead to considerations on how to plan PAPE training to be as effective as possible, taking into account the specific needs and training goals of athletes. It is also interesting to note that despite promising results, PAPE does not always lead to statistically significant performance improvements in every study, which may be due to differences in training protocols, the intensity of pre-activation exercises, or timing relative to the main effort [2]. Therefore, future research should consider these factors and carefully plan protocols to better understand the mechanisms and applications of PAPE in sports practice. Comparison with previous studies reveals that while some protocols such as

those involving plyometric exercises consistently yield positive results, others like isometric exercises show more variability. For instance, one study observed a significant improvement in jump height only in athletes with a specific muscle fiber composition, suggesting that PAPE may be more effective in certain subpopulations. These discrepancies highlight the importance of individualized approaches in the application of PAPE [2,36].

A recent study conducted by Masel and Maciejczyk provides interesting insights into the complexity and various effects of PAPE on jump outcomes among elite volleyball players. Despite a structured approach to inducing PAPE through conditioning activity—specifically deadlifts with added resistance—the results highlight the complex interaction between individual physiological responses and the effectiveness of such protocols [12].

A significant observation from the study is the considerable variability in individual responses to the same PAPE protocol. This phenomenon is crucial for understanding the effectiveness of interventions in performance sports but also underscores the need for personalized training programs. While the general protocol did not lead to significant improvements in jump power for all participants, a more detailed analysis revealed that a subgroup of athletes showed positive responses, particularly in the squat jump (SJ) compared to the countermovement jump [12]. This difference can be attributed to biomechanical similarities between the conditioning activity and SJ, which typically engage similar muscle groups and movement patterns.

Furthermore, the lack of a universally positive response among the study group highlights several factors that may influence the effectiveness of PAPE protocols. These include the specificity of the conditioning activity relative to the task performed, athletes' muscle fiber composition, and even the timing and intensity of the conditioning activity [37]. While accommodating resistance may be a valuable tool in enhancing performance, its application requires careful adjustment to each athlete's individual characteristics and capabilities [12]. The results underscore the importance of a holistic approach to training and conditioning athletes, prompting a rethink of the commonly used "one size fits all" methodology in training programs. Instead, they advocate for a more nuanced strategy that considers the unique physiological and biomechanical profiles of each athlete, thereby optimizing athletic outcomes while potentially reducing the risk of injuries associated with inappropriate training loads or activities that are not tailored to individual needs.

A review of the literature on the effects of PAPE highlights the significant role of various factors such as the type and intensity of conditioning activity, the time elapsed between its completion and the main effort, and the individual physiological characteristics of athletes in shaping the effectiveness of this phenomenon. Studies on PAPE are crucial for better understanding the physiological processes occurring in muscles after specific types of physical activity and for optimizing training protocols in sports.

4.1. Limitations of the Study

A wide variety of PAPE protocols were used in the selected studies, which complicates results comparison and determination of the best approach. Differences in intensity, duration, and type of activation exercises can significantly influence outcomes. Few studies investigate athletes' perception of effort and fatigue after PAPE application, which is crucial for understanding the impact of these exercises on athletes' overall feelings and well-being. Some of the included studies may have methodological limitations, such as small sample sizes, lack of control groups, or inconsistency in outcome assessment, affecting the credibility of conclusions.

4.2. Recommendations for Future Research

Future research should focus on several key areas. It is important to analyze the long-term effects of different PAPE protocols, particularly their impact on explosive strength and sports performance. Additionally, examining the optimal intensity of activation exercises and rest periods to maximize PAPE effectiveness is crucial. Another important aspect is the individualization of protocols, taking into account specific athlete characteristics,

such as muscle fiber composition and training level. Research should also compare the effectiveness of different types of activation exercises, such as isometric, isotonic, and plyometric exercises, and their impact on various types of jumps and explosive movements. Investigating the effects of PAPE on fatigue and athletes' subjective perceptions can help in better tailoring training sessions. Applying PAPE across different sports disciplines and deepening the understanding of its physiological mechanisms could contribute to optimizing training and enhancing sports performance. It has been emphasized that the mechanisms responsible for PAPE are complex and involve various physiological processes, such as increased muscle temperature, changes in muscle water content, and the recruitment of additional motor units. These processes collectively contribute to enhanced neuromuscular performance, although the specific pathways remain under investigation. Further research is needed to explore how variations in exercise intensity, rest intervals, and individual athlete characteristics influence the overall effectiveness of PAPE protocols.

5. Conclusions

This literature analysis indicates the presence of diverse pre-activation protocols, such as high-intensity conditioning, strength exercises, isometric drills, and plyometrics, all of which can enhance athletic performance. Despite the lack of conclusive evidence favoring one method over others, the effectiveness of PAPE varies and is influenced by factors such as the intensity of the conditioning activity, the rest period between conditioning and performance, and individual physiological characteristics. These findings suggest that PAPE protocols should be tailored to the specific needs of athletes to maximize their effectiveness. Future research should focus on long-term studies and include larger, more diverse populations to better understand the potential applications of PAPE across different sports and training contexts. The PAPE phenomenon is governed by complex physiological processes, suggesting the need for further research to deepen our understanding of its mechanisms and optimize training protocols. Limitations of this review include the small sample sizes in several included studies, the high heterogeneity of the protocols, and the focus on short-term outcomes. Future studies should explore the long-term effects of PAPE and investigate how different variables, such as training experience and gender, modulate its impact on performance. In response to the first research question, this review finds that different PAPE protocols can indeed yield varying effects on jump performance, depending on factors such as the intensity of the activation exercise. Regarding the second research question, key factors influencing PAPE effectiveness include athlete-specific characteristics such as muscle fiber composition and training level.

Practical Implications

The practical application of PAPE protocols can significantly enhance athletic performance in power-demanding sports such as basketball and volleyball. It is crucial to tailor these protocols to the individual needs of athletes, considering the specific demands of their sport and their training level. Personalizing PAPE optimizes neuromuscular readiness, minimizes fatigue, and maximizes training outcomes. For athletes requiring quick and powerful jumps, it is recommended to use PAPE protocols with submaximal loads at an appropriately selected time before key elements of training or competition. This approach helps optimize neuromuscular readiness without overloading the body and risking fatigue. Moreover, individualizing PAPE protocols can lead to maximizing training effects and improving athletic performance.

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