Ten-minute rest interval optimizes the effects of pre-activation on bench press performance in individuals with varying strength levels

Intervalo de descanso de diez minutos optimiza la preactivación del press de banca en individuos con diferentes niveles de fuerza

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Abstract

Introduction: Post-activation potentiation (PAP) is a strategy that acutely enhances performance following a high-intensity conditioning activity (CC). However, the optimal rest interval (RI) between the CC and main activity (MA), as well as the influence of individual strength levels, remains unclear, particularly in upper-body strength endurance protocols.
Objective: To compare the effects of pre-activation at different rest intervals (5, 10, 15, and 20 minutes) on bench press (BP) strength endurance performance and to analyze whether responses vary according to the participants' strength levels.
Methods: 30 men performed five sessions in randomized order. In four sessions, a 1RM set was used as CC before three sets of repetitions to failure at 85%1RM, each with a different RI (5,10,15, or 20min). A fifth session served as the control, without CC. Volume load (VL) and number of repetitions per set were recorded. Participants were also stratified by relative strength level (≥1.4 or <1.4).
Results: The 10-minute RI significantly improved total VL compared to control, 15-, and 20-min RIs ($p=0.009$, $p=0.003$, and $p<0.001$, respectively). Repetitions were significantly higher in the 10-min condition across all three sets ($p<0.05$). No significant interaction was found between strength level and PAP response.
Conclusion: A 10-minute rest interval between 1RM pre-activation and high-load BP appears to be the most effective strategy to enhance acute strength endurance performance. These effects were consistent across individuals regardless of strength classification, suggesting that PAP can be beneficial when RI are appropriately managed.

Keywords

Athletic performance; muscle strength; resistance training; weightlifting.

Resumen

Introducción: La potenciación post-activación (PAP) es una estrategia que mejora agudamente el rendimiento tras una actividad de acondicionamiento (AC) de alta intensidad. Sin embargo, el intervalo de descanso (ID) óptimo entre la AC y la actividad principal (AP), así como la influencia del nivel de fuerza individual, aún no están claros, especialmente en protocolos de resistencia de fuerza del tren superior.
Objetivo: Comparar los efectos de la preactivación con diferentes intervalos de descanso (5,10,15 y 20min) sobre el rendimiento en press de banca (PB) y analizar si las respuestas varían según el nivel de fuerza de los participantes.
Métodos: Treinta hombres entrenados realizaron cinco sesiones en orden aleatorio. En cuatro sesiones, se aplicó una serie al 1RM como AC, seguida de tres series al fallo con el 85%1RM, cada una con un ID distinto (5,10,15 o 20min). Una quinta sesión sirvió como control, sin AC. Se registraron la carga total (CT) y el número de repeticiones por serie. Los participantes también fueron estratificados por nivel de fuerza relativa (≥1.4 o <1.4).
Resultados: El ID de 10 minutos mejoró significativamente la CT total en comparación con el control, y con los ID de 15 y 20 minutos ($p=0.009$, $p=0.003$ y $p<0.001$). El número de repeticiones también fue significativamente mayor en la condición de 10 minutos en las tres series ($p<0.05$). No se encontró interacción significativa entre el nivel de fuerza y la respuesta a la PAP.
Conclusión: Un intervalo de descanso de 10 minutos entre la preactivación al 1RM y el PB con alta carga parece ser la estrategia más eficaz para mejorar el rendimiento agudo en resistencia de fuerza. Estos efectos fueron independientes de su clasificación por nivel de fuerza, lo que sugiere que la PAP puede ser beneficiosa cuando el ID se gestiona adecuadamente.

Palabras clave

Rendimiento atlético; fuerza muscular; entrenamiento de resistencia; levantamiento de pesas.

Introduction

In recent years, post-activation potentiation (PAP) has gained attention as a more targeted pre-activation strategy that temporarily enhances performance through prior high-intensity contractions (Blazevich & Babault, 2019; McGowan, Pyne, Thompson, & Rattray, 2015). This strategy appears to depend on the type of conditioning contraction (CC) to manifest a performance-enhancing phenomenon (Alves et al., 2021; Blazevich & Babault, 2019; Cardona-Gómez & Jaramillo, 2025; D. G. Sale, 2002). Research has revealed a significant impact of pre-activation with maximum loads on strength and power performance (Augustsson et al., 2003; Baker, 2003; Bazett-Jones, Winchester, & McBride, 2005; Boullosa et al., 2020; Brandenburg, 2005; Chiu et al., 2003; French, Kraemer, & Cooke, 2003; Gilbert & Lees, 2005; Gossen & Sale, 2000; Mangus et al., 2006). Additionally, the physiological mechanism behind PAP involves the phosphorylation of the regulatory light chain of myosin, making contractile proteins more sensitive to myoplasmic Ca2+ activation (Hamada, Sale, MacDougall, & Tarnopolsky, 2003; Houston, Green, & Stull, 1985; Requena et al., 2005), and the alterations in neural activation patterns, potentially increasing the recruitment of higher threshold motor units, improving performance in the main activity (Bird, Tarpenning, & Marino, 2005; Steele & Duke, 2003).

Several studies have examined the acute effects of CC on upper body performance, their findings have been inconsistent and sometimes contradictory (Alves et al., 2021; Baker, 2003; Brandenburg, 2005; Garbisu-Hualde, Gutierrez, & Santos-Concejero, 2023; Kontou, Berberidou, Pilianidis, Mantzouranis, & Methenitis, 2018; Krzysztofik & Wilk, 2020). These controversial results are often attributed to substantial methodological heterogeneity employed. Furthermore, much of the literature has focused on the effects of PAP protocols, particularly those involving high-intensity efforts, on neuromuscular parameters such as power output, rate of force development (RFD), endurance, and performance in explosive and sprint tasks (Castro-Garrido et al., 2020; López-Álvarez & Sánchez-Sixto, 2021), but not in strength endurance protocols (Bodden et al., 2019; Boullosa, Del Rosso, Behm, & Foster, 2018; Duthie, Young, & Aitken, 2002; Finlay, Bridge, Greig, & Page, 2022; Hamada, Sale, & Macdougall, 2000; McBride, Nimphius, & Erickson, 2005; Munshi et al., 2022; Smith, Fry, Weiss, Li, & Kinzey, 2001)

Specifically on our topic, Garbisu-Hualde et al. (2023) investigated the effects of a traditional PAP protocol (1 rep at 93% 1RM) on bench press (BP) performance to concentric failure using 80% 1RM, with a 6-minute rest interval (RI). The protocol significantly increased the number of repetitions (PAP: 10.83 ± 2.5 vs. CON: 9.76 ± 1.72; $p = 0.008$, ES = 0.5) and indicated greater effort tolerance, as shown by the reduced velocity in the final repetition and greater velocity loss across the set. These findings suggest that PAP may enhance acute training volume under specific conditions. However, only a single RI was examined (Garbisu-Hualde et al., 2023). In contrast, Krzysztofik et al. (2020) applied a PAP protocol (3x3 at 85% 1RM) followed by three sets to failure at 60% 1RM, with a 4-minute RI. No significant difference was observed in the total repetitions performed (PAP: 17.8 ± 6.8 vs. CON: 17.4 ± 7.0; $p = 0.38$), although time under tension increased significantly ($p < 0.01$), suggesting subtle neuromuscular effects (Krzysztofik & Wilk, 2020). These results differ from those of Garbisu-Hualde et al. (2023) and Alves et al. (2021), who reported performance improvements (PAP: 1.601 ± 504 kg; CON: 1.379 ± 364 kg) at shorter RIs (1.5 minutes), reinforcing the inconsistency in findings.

Thus, it appears that the manifestation of PAP may be sensitive to different characteristics that may include, the type, volume and intensity of CC and the RI between CC and main activity (MA) (Finlay et al., 2022); as well as, the MA configurations themselves (Finlay et al., 2022; Krzysztofik & Wilk, 2020; Krzysztofik, Wilk, Stastny, & Golas, 2020). Additionally, individual factors such as training level, strength, age, and sex may also influence PAP responses. (Borba, Ferreira-Júnior, Santos, Carmo, & Coelho, 2017). Among factors influencing PAP responses, RI appears crucial. Different RIs may impact PAP responses even with an appropriate CC, adding complexity.

These findings suggest a growing but still insufficient or contradictory body of evidence, specifically addressing PAP effects on strength endurance (Alves et al., 2021; Garbisu-Hualde et al., 2023; Krzysztofik & Wilk, 2020). Furthermore, evidence suggests that the magnitude of PAP responses may be modulated by the individual's strength level. Stronger individuals often present greater responses, possibly due to a higher proportion of fast-twitch muscle fibers, superior rate coding, and increased capacity to recruit high-threshold motor units (Seitz, de Villarreal, & Haff, 2014; Tillin & Bishop, 2009). In contrast, weaker individuals may have a lower fatigue resistance and slower recovery from CC, which may attenuate or mask the potentiation effect (Chiu et al., 2003). Additionally, stronger individuals tend to tolerate higher loads and recover faster, which is essential for the expression of PAP, where fatigue and potentiation coexist and interact dynamically (Wilson et al., 2013).

Although some studies have examined the relationship between PAP and strength levels in the back squat (Millender, Mang, Beam, Realzola, & Kravitz, 2021; Seitz et al., 2014), none have investigated the effects of multiple RI strategies among individuals with varying strength levels. Thus, strength level appears to be a moderating factor in PAP protocols, justifying the comparison between groups of distinct force capacities. Our primary objective was to compare pre-activation effects at different RIs (5, 10, 15 and 20 min) on BP strength endurance performance. Secondarily, we explore potential differences between low and high strength groups. We believe that different potentiation responses between different RIs will occur, with differences between strength levels.

Method

Experimental Approach to the Problem

The present study was carried out based on the guidelines for cross-sectional studies STROBE Statement (https://www.strobe-statement.org/checklists)(Malta, Cardoso, Bastos, Magnanini, & Silva, 2010). The study followed Resolution 466/2012 of the National Health Council and was approved by the Research Ethics Committee (nº 5.466.875). All participants were recruited by convenience and signed a consent form containing pertinent information on the experimental procedures as well as the possible risks and discomforts involved in the study. This information was also verbally explained in a detailed manner. After selection, acceptance and understanding of the risks inherent to high-intensity strength exercise, all participants signed the consent form. Flowchart 1 presents the results of recruitment, entry, eligibility and exclusion of participants of experimental collection.

A randomized controlled cross-sectional design was used in this study. A set of 1RM (100%) was used as a condition contraction (CC) to verify its effect on the maximum number of repetition (RM) with 85% of 1 RM in three subsequent series. There was one visit for familiarization, followed by three visits to determine the 1RM load, with the subsequent execution of four experimental visits and one control, totaling nine visits. The group's internal data regarding reliability analysis showed an excellent rating for RM stability during the BP exercise (CCI > 0.90) as observed in the systematic review (Grgic, Lazinica, Schoenfeld, & Pedisic, 2020) for trained participants. The primary outcomes of this study involve the dependent variables: Number of repetitions performed in each series and volume load (sum of repetitions in the three series x workload). As a secondary outcome, percentage of potentialization between different training levels (low strength x high strength group) were evaluated.

Participants

The study included 30 males apparently healthy. All participants were recruited via public call in just one step at a gym located in the west zone of Rio de Janeiro (Brazil). The complete duration of the study was approximately 6 months, according to participants arrive. As an inclusion criterion, participants must have a minimum of 2 years of strength training experience, who performed BP exercises a minimum of twice a week and lifted workload for BP above 1.2 of body mass as a reference (E. R. T. Santos Junior et al., 2021). The exclusion criteria consisted of the presence of any injury, surgery on the joints involved in the study, use of supplements and anabolic steroids or any other drugs that could interfere with the outcome variables. The sample size was calculated considering the statistical model that will be used to compare the post activation potentiation responses between the different strength level groups: high and low, as well as between the different recovery intervals: control, 5, 10, 15 and 20 minutes. Thus, repeated measures ANOVA with interaction between two groups (high and low level of force) and intra issues, that is, five moments: control, 5, 10, 15 and 20 minutes, was applied. In addition, an α of 5% was considered for analysis and an effect size of f=0.25 and without correction for sphericity, providing a statistical power of 81,7% (G*Power, Version 3.1.9.4). Therefore, 30 individuals provided the necessary statistical power for the analyzes. A description of the subjects is presented in Table 1.

Withdrawal Criteria

Participants would automatically be removed from the study if they did not fully comply with the evaluation processes or did not complete at least three of the experimental sessions, or do not carry out the experimental sessions more than a week apart. Participants were also informed that they were free to leave the experiment without harm at any time.

Procedure

Experimental Protocol

After three initial visits to determine workload stability, five experimental sessions were completed in which the subjects executed three sets of RM with 85% of 1 RM as the MA. A two-minute time was offered between sets. In four sessions, one set of 1 RM (previously determined) was performed as the CC, preceding the three sets of RM (to failure), only differing in the duration of RI between the CC and MA, which was 5, 10, 15, or 20 minutes. A fifth session in which the CC was not carried out served as the control. The experimental control procedure only performed the three series without the influence of any previous interventions. All of the sessions were carried out in random order and separated by intervals of 72 to 96 hours. During the experimental treatment, the same safety procedures and controls were used as the tests of 1 RM. During the experimental session, no previous activity was performed before the CC (there was no muscle warm-up strategy). Likewise, in the control, no warm-up was performed before the MA. At all visits, participants were encouraged to perform to the best of their ability. All procedures were carried out at the same time of day under the same temperature and humidity conditions. During the intervention, participants were asked to abandon their routines related to strength training but maintain their eating habits.

Minimizing the effects of fatigue

To minimize potential residual fatigue between sessions and ensure the validity of the potentiation effects observed, several methodological precautions were adopted. All experimental sessions were scheduled with a minimum interval of 72 hours and a maximum of 96 hours. Participants were instructed to abstain from any resistance training throughout the intervention period, especially exercises involving the muscle groups engaged in the BP. Furthermore, all sessions were conducted at the same time of day, under consistent environmental conditions, and participants were advised to maintain regular sleep and dietary habits. Although no formal fatigue assessment was conducted, the lead researcher maintained close contact with participants and requested that they report any issues related to rest or recovery prior to each session.

Anthropometry and Body Composition

Height was measured (SECA® Gmbh, Hamburg, Germany) with the volunteer in a standing position and barefoot, with the ankles, calves, buttocks, scapula, and head leaning on a wall. The position of the head accompanied Frankfurt's plan, and stature was measured at the moment of inhaling air. Body mass was measured (Toledo 2096 PP, São Bernardo do Campo, Brazil) while the participants wore light clothes. Relative body fat was estimated by the sum of seven skinfolds (chest, axilla, triceps, subscapular, abdomen, suprailium and front thigh skinfold) using a skinfold caliper (Sanny™) and applying the equation and protocol proposed by Jackson & Pollock's (Jackson & Pollock, 1978). The skinfolds were collected at each point in rotational sequence, beginning on the right side of the body, and the median value was recorded.

1 RM Testing

To decrease learning effects, three 1 RM tests were performed; two were performed for familiarization to establish the maximum workload for the BP. The tests were separated by a minimum interval of 72 hours and a maximum interval of 96 hours. Individuals maintained their training routine but avoided specifically training or exercising the muscles involved in the BP (pectoralis major, anterior deltoid, and triceps) in the 48 hours prior to the test. A warm-up activity preceded the 50% of 1 RM estimated by the individual. It is important to emphasize that the specific warm-up was only used for 1 RM test. Due to the interference that flexibility exercises can play on the strength performance, no stretching was done prior to the test (Rubini, Costa, & Gomes, 2007). To establish maximum dynamic strength, the procedures recommended by Kraemer et al.(Kraemer & Ratamess, 2004) were used in the protocol. Aiming for greater accuracy in the establishment of the mobilized load, the mass of all the plates and bars used during the study were previously measured in a Filizola® (Brazil) scale with an accuracy of 0.1 kg.

Bench Press (BP) Exercise

The participant was instructed to position himself on the bench in a supine position with his feet on the ground. The BP were executed using the standard 5-point body contact position technique (head, back, and buttocks firmly on the bench with both feet flat on the floor). The initial position involved subjects holding the barbell with a self-selected grip width and with their elbows fully extended. From this position, they lowered the bar to touch the chest and immediately after pressed the bar as fast as possible until their elbows reached full extension (touch-and-go technique). The arch of the lower back was asked to be minimized in both BP variants. The BP was performed with a 180 cm bar. Two investigators were positioned on both sides of the bench and responsible for taking the bar out of the support and starting the test. A third investigator was responsible for ensuring that the volunteer was performing the horizontal shoulder extension within the established range.

At the sign of concentric fatigue, the investigators interceded, returning the bar to the support. It was only considered a complete repetition if the movement was performed in a continuous way. The occurrence of 3 seconds of isometrics invalidated the repetition.

Low and High-Performance Stratification

To verify the influence of strength levels on potentiation, the subjects were divided into two groups, stratified according to both absolute and relative strength (load lifted/body mass). For this purpose, participants were ranked based on their relative strength values and grouped into tertiles. To maximize contrast between groups and reduce overlapping variability, the middle tertile (moderate strength) was excluded from subsequent analyses. The group classified as low strength (Low; n = 10) consisted of individuals in the first tertile, with a relative strength index below 1.4. Conversely, the high strength group (High; n = 10) included participants in the third tertile, with a relative strength index above 1.4. This cut-off point was based on previous studies that considered a relative strength of 1.4 or greater as indicative of well-trained individuals in upper-limb resistance exercises (E. R. Santos Junior et al., 2021; Seitz et al., 2014). By removing the intermediate group and focusing on the extreme tertiles, the aim was to enhance statistical sensitivity and explore whether individuals with higher strength capacities exhibit different PAP responses when compared to their weaker counterparts. Although this binary classification does not capture the full spectrum of individual variability, it provides a valid and commonly used methodological approach in cross-sectional studies to explore strength-dependent effects.

Volume Load Calculation

The volume load (VL) was calculated based on the total work performed in the three sets, using the following formula: total VL = [number of repetitions × external load to 85% of 1RM (kg)], as suggested by Peterson et al (Peterson, Pistilli, Haff, Hoffman, & Gordon, 2011). Only repetitions completed within the previously established required range of movement were counted.

Randomization and Allocation Process

Simple randomization was applied. The randomization process was done manually using papers with the designation of the experimental session inserted into an opaque bag. One of the evaluators (not a direct participant in the collection) organized five numbers on paper, referring to the five experimental sessions. It was requested that the third evaluator sequentially remove each number, assigning the experimental sessions in which each participant would be treated. The researchers responsible for the collection were only aware of the procedure before the collection began. Participants were aware of the RI used due to the nature of the protocol; however, it was only at the time of intervention that they knew how long they should rest. Participants were reminded not to disclose their group allocation during follow-up assessment.

Blinding and Data Analysis and Treatment

Due to the practical nature of the protocol, blinding of participants was not feasible, as RI were clearly visible in the training environment. However, to reduce bias, different researchers conducted the intervention sessions and the outcome measurements. The researchers responsible for instructing participants were unaware of the specific hypothesis being tested. Additionally, all data were analyzed by a third investigator who was blinded to group allocation throughout the entire data treatment process. This approach aimed to preserve blinding at the analysis stage and minimize observer bias during testing.

Data analysis

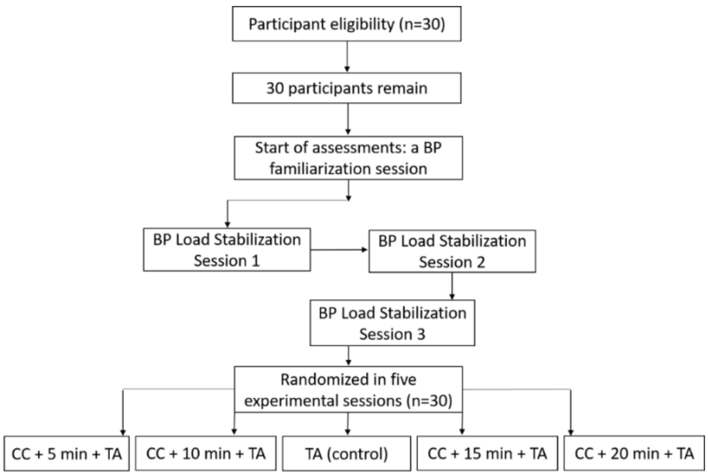
The normality and homogeneity of variance were tested using the Shapiro–Wilk and Levene tests, respectively. As the data presented a Gaussian distribution, they were expressed as the mean ± standard deviation (SD) and 95% confidence interval ($CI^{95\%}$). In order to compare the number of RM performed per set and to determine the differences in percentage change (%) of potentiation in the experimental conditions, ANOVA for repeated measures was carried out. ANOVA for repeated measures was also used to determine the differences in the VL performed at the end of each condition.

ANOVA (2 x 5, strength level x experimental condition) was performed to verify the influence of strength levels on the differences in workload volume. To determine if the strength levels influenced the magnitude of potentiation, ANOVA (2 x 4, strength level x experimental condition) was performed. These two analyses were carried out for absolute and relative strength. To compare the differences found in all the analyses, Bonferroni's post hoc test was used. Additionally, Cohen's d effect size was calculated to estimate the magnitude of differences between experimental conditions. According to Cohen's conventions, values were interpreted as small (≥ 0.20 and < 0.50), medium (≥ 0.50 and < 0.80), or large (≥ 0.80). A significance level of $p \leq 0.05$ was adopted. All data were analyzed using SPSS version 22.0.

Results

A description of the subjects is presented in Table 1 and Flowchart 1 presents the results of recruitment, entry, eligibility, and exclusion of participants of experimental collection.

Figure 1. Flow of occurrences throughout the study.



Source: Author

Table 1. Descriptive characteristics of volunteers (n = 30).

Variables	Mean ± SD
Age (years)	25.0 ± 5.8 (22.8–27.1)
Body Mass (kg)	78.5 ± 11.2 (74.3–82.6)
Height (cm)	174.8 ± 8.8 (171.5–178.0)
Body fat (%)	16.1 ± 5.0 (14.2–17.9)
Lean body mass (kg)	65.6 ± 7.8 (62.6–68.5)
BP 1 RM (kg)	113.8 ± 19.6 (106.4–121.1)

the values are reported as mean ± SD ($CI^{95\%}$).

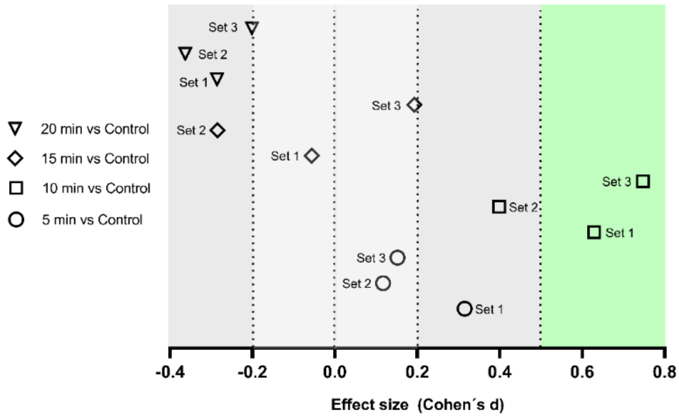
Table 2 presents the number of RM performed in the 3 sets for each condition. The 5- and 10-min RI enabled the performance of a significantly greater number of RM than the control condition (p = 0.007). Figure 1 shows the effect size between RI vs. control. Figure 2 demonstrates that the 10-min RI performed an VL significantly greater than the control (2030.13kg ± 485.10 vs. 1751.58kg ± 412.72, respectively; p = 0.009).

Table 2. Number of RM in the sets on the BP for each experimental condition.

Condition	Set 1	Set 2	Set 3
Control	7.6 ± 1.8 (6.9–8.2)	6.1 ± 1.6 (5.5–6.7)	4.3 ± 1.1 (3.8–4.7)
5 minutes	8.2 ± 2.0* (7.4–8.9)	6.3 ± 1.8* (5.6–6.9)	4.5 ± 1.5 (3.9–5.0)
10 minutes	8.9 ± 2.3* (8.0–9.7)	6.8 ± 1.9* (6.0–7.5)	5.2 ± 1.3* (4.7–5.6)
15 minutes	7.5 ± 1.8 (6.8–8.1)	5.6 ± 1.9 (4.8–6.3)	4.6 ± 1.9 (3.9–5.3)
20 minutes	7.1 ± 1.7 (6.4–7.7)	5.5 ± 1.7 (4.8–6.1)	4.0 ± 1.8 (3.3–4.6)

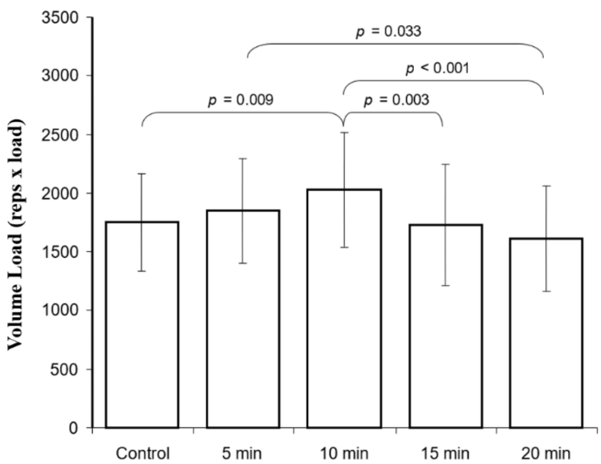
* Statistically significant difference (p<0.05), the values are reported as mean ± SD (CI[95%]).

Figure 2. Effect size (Cohen's *d*) for the number of repetitions performed in each set of the BP across experimental conditions compared to the control.



Legend: Each symbol represents the effect size for a specific rest interval (RI) condition—5, 10, 15, and 20 minutes—relative to the control. The sets (Set 1, Set 2, and Set 3) are labeled accordingly. Positive values indicate performance improvements compared to the control condition. The shaded green area denotes a large effect size (Cohen's d ≥ 0.50). According to Cohen's classification, values from 0.20 to 0.49 are considered small, values from 0.50 to 0.79 are medium to large, and values below 0.20 are considered negligible or trivial.

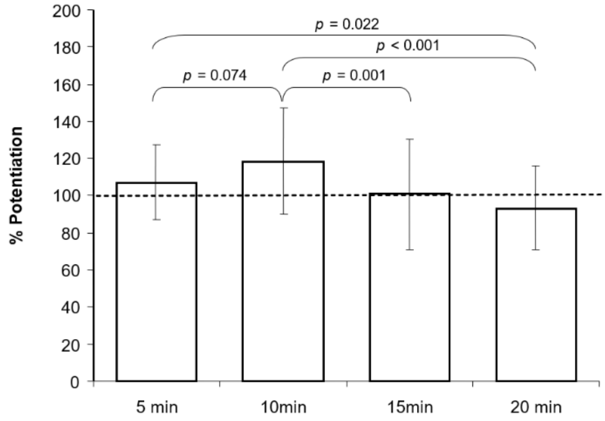
Figure 3. VL (sum of repetitions in the three sets x workload) in five experimental conditions



The values are reported as mean ± standard deviation; Source: Author.

Figure 4 demonstrates that positive percentage changes occurred only in the 5 and 10min RI with a non-significant difference between them, although marginal (p = 0.074). On the other hand, the 20-min RI produced a decrease in performance while the 15-min RI did not produce changes in potentiation.

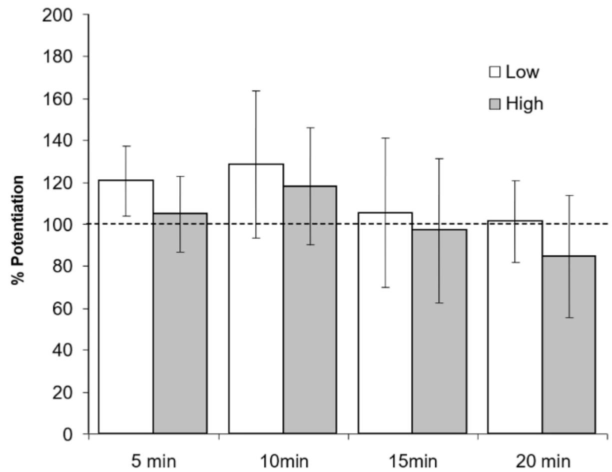
Figure 4. Percentage change of the VL in the different experimental conditions.



The values are reported as mean ± standard deviation; Source: Author.

The low strength group was significantly different from the high strength group when comparing absolute strength (96.18 ± 6.89 kg vs. 132.92 ± 20.52 kg; p < 0.001) and relative strength (1.24 ± 0.11 vs. 1.69 ± 0.14; p < 0.001). There was no interaction between the relative strength level and the experimental conditions in terms of the VL (F4.72 = 0.1944; p = 0.94) and % change in potentiation (F3.54 = 0.8087; p = 0.97). Similarly, there was no interaction between the absolute strength level and the experimental conditions in terms of VL (F4.72 = 0.6808; p = 0.60) or % change in potentiation (F3.54 = 0.2241; p = 0.87). For each experimental condition, strength levels were compared in pairs and separately for the dependent variables VL and % change in potentiation. Figure 4 demonstrates that the % change in potentiation at the 5-min condition of the low strength group showed a non-significant difference, albeit marginal, compared to the high strength group (120.61 ± 16.74% vs. 104.92 ± 17.90%, respectively; p = 0.058).

Figure 5. Percentage change of the VL in relation to the relative force level (load lifted divided by body mass).



The values are reported as mean ± standard deviation; Source: Author.

Discussion

The objective of this study was to verify the acute effect of pre-activation in different RI between the CC and MA on the performance of RM on the BP. Based on comparisons, previous CC at 5- and 10-min RI enhanced performance compared to the control, although 15- and 20-min, no. In addition, there was a significant increase in the number of reps in the first two sets of BP for 5- and 10-min RI, with only the 10 min interval increasing performance until the last set performed.

Primary Outcome

Most studies investigating PAP have focused on performance variables such as twitch potentiation (Gilbert & Lees, 2005; Hamada et al., 2000; Requena et al., 2005), power (Bazett-Jones et al., 2005; Duthie et al., 2002), and rate of force development (Bazett-Jones et al., 2005), often using explosive or isometric tasks. However, limited evidence has examined PAP effects on strength endurance performance in multi-set protocols under submaximal loads, such as the BP performed to failure (Alves et al., 2021; Garbisu-Hualde et al., 2023; Krzysztofik & Wilk, 2020). These studies attempted to establish the best method capable of producing PAP and determine the RI between pre-activation and target exercise at which the PAP manifested or dissipated (Chiu et al., 2003; Hamada et al., 2003; O'Leary, Hope, & Sale, 1997; Steele & Duke, 2003). In this way, our findings help address this gap by showing that a pre-activation protocol involving a single 1RM effort, when followed by a 10-minute RI, significantly improved performance across all three sets of BP at 85% of 1RM.

Specifically, the 10-minute condition resulted in a greater number of repetitions in each set and a higher total VL compared to the control, 15-minute, and 20-minute conditions ($p < 0.05$). The 5-minute condition also improved performance in the first two sets, but only the 10-minute interval maintained the performance enhancement through the third set. This suggests that 10 minutes may provide the optimal balance between residual fatigue from the conditioning activity and the potentiation effect. Additionally, the longer intervals (15 and 20 minutes) may have allowed the potentiation effects to dissipate, while the shorter intervals (e.g., 5 minutes) may not have provided sufficient time for partial recovery, especially in participants with lower fatigue resistance. These dynamics highlight the dual role of fatigue and potentiation as competing forces during repeated efforts, particularly in high-intensity protocols. As suggested by Wilson et al. (2013), the optimal window for performance enhancement occurs when potentiation remains elevated while fatigue has been adequately reduced, a condition seemingly met only in the 10-minute RI in our study (Wilson et al., 2013).

The differences observed across sets also shed light on the temporal dynamics of fatigue. While set 1 reflected an acute potentiation response, sets 2 and 3 revealed a progressive decline in performance in all conditions except the 10-minute RI. This may be explained by cumulative fatigue, particularly in the control and longer RI protocols, where the potentiation effect likely diminished, and fatigue became more prominent. Mechanistically, the accumulation of metabolites (Pi) and impaired Ca^{+2} handling during repeated submaximal efforts may reduce force output (Allen, Lamb, & Westerblad, 2008; Steele & Duke, 2003; Sweeney, Bowman, & Stull, 1993). Therefore, the third set appears to be a critical indicator of whether PAP was sufficient to counteract fatigue over time. The preserved performance in the 10-minute condition supports the hypothesis that this interval maximizes potentiation while allowing adequate recovery.

Our findings are in line with previous studies that also reported positive effects of post-activation potentiation on BP performance (Alves et al., 2021; Garbisu-Hualde et al., 2023). Garbisu-Hualde et al. (2023), for example, used a single repetition at 93% of 1RM followed by a 6-minute RI and observed a significant increase in the number of repetitions performed at 80% of 1RM. Similarly, Alves et al. (2021) applied a 1RM conditioning stimulus with a shorter RI (1.5 minutes) and reported improved performance in total training volume at 75% of 1RM. Although these studies and ours adopted maximal loads as conditioning activity and demonstrated beneficial outcomes, our protocol differed by systematically testing multiple RI (5, 10, 15, and 20 minutes) and assessing performance across three consecutive sets at 85% of 1RM.

Thus, it seems that choosing each variable, RI, MA, and the type of MA is the defining factor of the PAP results (Baker, 2003; Chiu et al., 2003; Gilbert & Lees, 2005). Each of these is important when choosing which variable to use, suggesting that a combination of the three factors can produce better results. It is noteworthy that post-activation potentiation can manifest itself in the form of strength, power and strength endurance and that different pre-activation stimuli and RI may manifest differently in relation to the investigated potentiation measures.

Secondary Outcome

Although it is often hypothesized that individuals with greater strength may be more responsive to PAP, particularly due to enhanced neural recruitment capacity, evidence remains mixed, especially when the focus shifts from power-oriented outcomes to strength endurance tasks. In the present study, participants were stratified based on relative strength and divided into high and low strength groups using a tertile approach. A cut-off value of 1.4 (1RM/body mass) was used, with values ≥1.4 classified as high strength and <1.4 as low strength, in accordance with prior research identifying this threshold as representative of well-trained individuals in upper-body resistance exercises (Santos Junior et al., 2021; Seitz et al., 2014). Despite significant differences between groups in both absolute and relative strength ($p < 0.001$), no interaction effects were observed between strength level and RI condition for either volume load or percentage change in potentiation. This suggests that, under the specific parameters of our protocol, multiple sets to failure at 85% of 1RM in the BP, PAP-related improvements were not significantly influenced by the strength classification.

Interestingly, although the literature frequently reports greater PAP responsiveness in stronger individuals (Seitz et al., 2014; Tillin & Bishop, 2009), our results showed a marginally higher potentiation effect in the low strength group at the 5-minute RI ($p = 0.058$), albeit not statistically significant. This challenges the notion that stronger individuals always benefit more from PAP and raises the possibility that recovery kinetics, fatigue tolerance, and exercise modality may play a more complex role than previously assumed. It is also possible that the time course of potentiation differs depending on the muscle group, load characteristics, and training background, which might explain the variability observed across studies.

Some investigations have attempted to classify PAP responders based on absolute strength (Blazevich & Babault, 2019) or general training level (Chiu et al., 2003), but with inconsistent findings. Gourgoulis et al. (2003) reported that stronger participants tended to perform better following PAP, although results did not reach statistical significance (Gourgoulis, Aggeloussis, Kasimatis, Mavromatis, & Garas, 2003). Similarly, Duthie et al. (2002) used a different classification strategy, dividing subjects into athletes and non-athletes, and observed performance differences that were not evident before stratification (Duthie et al., 2002). In our study, the absence of significant differences when stratifying by relative strength aligns with the findings of Gossen and Sale (2000), who also failed to detect meaningful differences between groups based on absolute strength (Gossen & Sale, 2000). However, it is important to note that many of these studies focused on explosive or power-oriented outcomes, such as vertical jump or sprint performance. Gourgoulis et al. (2003), for instance, evaluated PAP effects on muscle power following half-squat exercises, not strength endurance under submaximal loads, as in our study. This distinction reinforces the idea that different manifestations of muscular performance (power, strength, or endurance), may respond differently to PAP depending on the RI, stimulus type, and muscle group involved.

In light of these findings, our results contribute to the growing body of evidence suggesting that PAP responsiveness may not solely depend on strength level, especially in protocols involving upper-body strength endurance with submaximal loads.

Potential Mechanisms of Action

The present study did not investigate the physiologic mechanisms that could explain the results; however, other studies allow us to pose some hypotheses. Some studies (Alves et al., 2021; Boullosa et al., 2018; Mangus et al., 2006; D. Sale, 2004; D. G. Sale, 2002), have suggested that the principal mechanism of PAP is the phosphorylation of the light chain regulating the myosin head, which causes alterations in the force-pCa^{2+} relationship. This can describe the changes that make the contractile proteins more or less sensitive to myoplasmic calcium concentrations. Transitory calcium increases can activate the myosin light chain kinase through Ca^{2+}-calmodulin, leading to the phosphorylation of the regulating light chain. This, in turn, diminishes the interaction of the myosin head with the thick filament, causing a separation in the direction of the thin filament and increasing the likelihood of an interaction that would facilitate the formation of the actomyosin complex (Sweeney et al., 1993).

In normal conditions, the tension produced during a muscle contraction is proportional to the myoplasmic Ca^{2+} concentration (Steele & Duke, 2003). Consequently, the myoplasmic Ca^{2+} concentration levels, in relation to the tension, promote the production of strength. A drop in the levels of Ca^{2+} in the myoplasm decreases the tension produced. PAP seems to occur before a decrease in Ca^{2+} concentration levels (Vandervoort, Quinlan, & McComas, 1983; Williams, 1990), leading to reduced energy consumption with the reaccumulation and liberation of Ca2+ by the sarcoplasmic reticulum and a delay in fatigue in sub-maximum contractions (Williams, 1990).

Some factors influence the Ca^{2+} concentrations of the sarcoplasmic reticulum in the myoplasm. For instance, as the firing frequency of the alpha motor neurons increases, the quantity of Ca^{2+} released into the sarcoplasm increases (Bazett-Jones et al., 2005). Another factor that can influence Ca^{2+} concentrations is the intracellular levels of inorganic phosphate (Pi), resulting from the breakdown of phosphocreatine during muscle contractions, a process that could explain fatigue instauration (Allen et al., 2008; Blazevich & Babault, 2019; Sweeney et al., 1993).

Another mechanism that has been suggested seems to be due to alterations in the pattern of neural activation, leading to an increase in the recruitment of higher threshold motor units, that is, greater amplitude of the H-reflex, thus improving performance in the main activity (Bird et al., 2005). Therefore, the possible physiological events that may be involved in the results of the present study are: (a) decreased energy consumption (with the release and reaccumulation of Ca^{2+} from the myoplasm to the sarcoplasmic reticulum) in relation to the tension needed to support the contraction can occur at sub-optimal levels of Ca^{2+}, leading to a delay in fatigue; (b) due to a deviation to the left of the force-pCa^{2+} relationship, the tension needed to generate a specific number of repetitions can be maintained during fatigue1. This means that even with sub-optimal Ca^{2+} concentrations, as a function of the previously explained fatigue process, possible potentiation mechanisms can allow the maintenance of long-term strength production. Therefore, in any of the hypotheses, an increase or maintenance of strength in sub-optimal Ca^{2+} levels would occur, leading to an improvement of muscle force (McGowan et al., 2015).

Limitations

Although positive results were found, it is important to highlight potential limitations of the study. First, although the statistical power calculation indicated that 30 participants were sufficient, the sample may not be representative of broader populations, such as elite athletes or beginners in resistance training. As such, caution is warranted when generalizing these findings beyond recreationally trained males with at least two years of consistent training experience. Second, the binary classification into high and low strength groups may not capture nuances in individuals with intermediate strength levels, potentially overlooking gradual strength–performance relationships. Third, our study is based on theoretical mechanisms (e.g., myosin light chain phosphorylation, neural drive modulation) to explain PAP, but no physiological or neuromuscular data were collected to confirm these hypotheses.

In addition, the acute design provides a snapshot of performance enhancement and does not allow for extrapolation to chronic adaptations. Therefore, we cannot infer whether long-term use of pre-activation protocols with different rest intervals would result in superior gains in muscular endurance or strength. Another important consideration is that the study focused exclusively on trained men, limiting its applicability to female populations or individuals of different age ranges.

Furthermore, potential methodological biases may have influenced the findings. Although randomization and partial blinding strategies were implemented, complete blinding was not feasible due to the visible nature of RI and the structure of the intervention. Additionally, our study did not include a specific analysis of individual responsiveness to PAP. This limits the ability to distinguish between responders and non-responders, a relevant factor considering the known interindividual variability in PAP expression. Future studies should incorporate individualized response profiles or cluster-based analyses to better understand the variability in adaptation to different pre-activation strategies.

Conclusions

In summary, the present study demonstrated that a 10-minute RI following a 1RM pre-activation protocol was the most effective strategy to enhance acute strength endurance performance in the BP exercise, especially when performed at 85% of 1RM over multiple sets. This condition consistently improved total volume load and repetition performance across all three sets, outperforming shorter and longer intervals, as well as the control condition. Importantly, these benefits were observed regardless of the participants' relative strength level. Future research should explore long-term adaptations to PAP-based protocols and evaluate effects across different populations (e.g., females, untrained individuals, athletes).

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