INNSPUB

International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print) 2222-5234 (Online)
http://www.innspub.net
Vol. 21, No. 6, p. 217-230, 2022

RESEARCH PAPER OPEN ACCESS

Eliciting post activation potentiation to enhance jump and sprint performance in trained athletes-systemic review and meta-analysis

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Key words: Post activation potentiation, Jump, Sprint, Speed, Performance in different combinations

http://dx.doi.org/10.12692/ijb/21.6.217-230 Article published on December 06, 2022

Abstract

Post-activation potentiation (PAP) is an occurrence in which muscle strength and power are acutely increased following a pre-load stimulus encouraging post-activation potentiation to improve trained athletes' jump and sprint performance. For PAP, several explanations have been offered. Short-duration tasks that need the most strength or power performed prior to the main activity. In an effort to improve performance by inducing post-activation potentiation. Additionally, weaker and stronger people appear to have varied PAP reactions; however, it is yet unclear how these people react to the various parts of a strength-power-potentiation complex. This study's objective was to evaluate prior research on post-activation potentiation's effects on athletic performance and to provide coaches and sports scientists with advice on how to comprehend the function of loads properly and rest ratios in eliciting post-activation potentiation to improve trained athletes' jump and sprint performance. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses were used to guide the conduct of this systemic review and meta-analysis (PRISMA). Databases including PubMed, Web of Science, PEDro, CINAHL, and Science Direct were used to compile the studies. The last search was performed on January 31, 2022. Post-activation potentiation, jump, sprint, speed, and performance were all used in various combinations. This study's findings indicate that post-activation potentiation has no appreciable impact on athletes' ability to sprint and jump. It is not a given that the presence of PAP will lead to enhanced volunteer performance. Regarding the impact of PAP on jump and sprint performance, there are conflicting findings in the existing literature. The results of this meta-analysis is that heavy back squats that elicit post-activation potentiation do not significantly improve countermovement jump height or the 5- and 10-meter sprint timings.

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Introduction

Post-activation potentiation (PAP) is an occurrence in which there is a critical enhancement of muscle performance in terms of strength and power after a pre-load stimulus (M. Hodgson *et al.*, 2005). There are various theories given for PAP. There is thought to be an increased because of the phosphorylation of myosin regulatory light chains, actin and myosin molecules are more sensitive to the presence of calcium (M. J. Hodgson *et al.*, 2008). increased excitability of α-motor neurons (Gullich & Sehmidtbleicher, 1996), increased synchronization of motor units, reciprocal inhibition of antagonist muscles (Baker, 2005; Ebben *et al.*, 2000), and shortening of pennation angles, enhancing force transfer to the tendon (Gołaś *et al.*, 2016). Various stimuli can be used to induce PAP, including traditional dynamic resistance training (Kilduff *et al.*, 2008; Wilson *et al.*, 2013), maximum voluntary isometric contraction (Kovačić *et al.*, 2010; Skurvydas *et al.*, 2019), or plyometric exercise (Turner *et al.*, 2015). The back squat has been utilized in numerous studies as a preconditioning stimulus to induce PAP and improve strength and power performance due to its wide use by athletes, coaches, and researchers (Chiu *et al.*, 2003; Esformes & Bampouras, 2013; Kilduff *et al.*, 2007; Smilios *et al.*, 2005; Witmer *et al.*, 2010).

There is increased activation of the gluteus maximus with increasing squat depth (Caterisano *et al.*, 2002), and this muscle is crucial for the countermovement jump as well. (Fukashiro & Komi, 1987) and thus has a direct impact on functional performance. Different variations of the squat depending on the depth have been used. In addition to squat depth, different variations of load have also been used. Some studies have used heavy squats, i.e., > 80% of 1 RM (Gourgoulis *et al.*, 2003; Rixon *et al.*, 2007), while others used lighter loads, i.e., 40% of 1RM (Hanson *et al.*, 2007). Countermovement jump (CMJ) and sprint tasks performed in many sports and used for testing lower limb power. Various potentiating stimuli have been used in research to enhance CMJ and sprint performance, including resistance exercise, plyometrics, and electrical stimulation (Gourgoulis *et al.*, 2003; Witmer *et al.*, 2010). The potentiation and fatigue exist together after completing an exercise. After some time, fatigue starts to decrease and potentiation remains, thus resulting in performance enhancement (Rassier & Mac Intosh, 2000). There is a balance between fatigue and potentiation after a conditioning activity that depends upon many factors, including training experience (Chiu *et al.*, 2003), rest period length (Kilduff *et al.*, 2008), type of exercise, training intensity, and volume of conditioning activity (Sale, 2002). Shorter rest periods, i.e., <1 min, can result in performance enhancement after a low volume potentiating protocol (Tillin & Bishop, 2009), whereas longer rest periods of >3 min are required after high volume potentiating protocols (Wilson *et al.*, 2013). Additionally, the magnitude of PAP depends on factors such as age, sex, the triggering stimulus, fiber type, the degree of fatigue, and the level of training (Batista *et al.*, 2011; Hamada *et al.*, 2003; Wilson *et al.*, 2013).

There are also a lot of differences in the rest periods given after the preload stimulus. Some studies suggest that rest periods of less than 20 seconds can result in vertical jump performance enhancement (Arabatzi *et al.*, 2014), while a meta-analysis revealed that rest periods of 3–7 minutes are more beneficial (Wilson *et al.*, 2013). There is an inverse relationship between relative strength and the rest periods required to elicit PAP. More trained individuals with more strength require shorter rest periods to elicit PAP than weaker individuals (Jo *et al.*, 2010). And also, the magnitude of PAP depends upon individual characteristics; e.g., stronger individuals show a higher amount of PAP as compared to their weaker counterparts (Seitz & Haff, 2016). Some studies suggest that the ideal recuperation period between a stimulus for preload and a burst activity for performance enhancement is 8 minutes (Bevan *et al.*, 2009; Kilduff *et al.*, 2007, 2008).

This study's objective was to evaluate prior research on post-activation potentiation's effects on athletic performance and to provide coaches and sports scientists with advice on how to comprehend the function of loads properly and rest ratios in eliciting post-activation potentiation to improve trained athletes' jump and sprint performance. The goal of this meta-analysis to define effect of strong back squat induced Post activation potentiation on recommitting jump height and sprint performance of athletes and to define the optimal rest periods after PAP stimulus for maximum performance enhancement.

Materials and methods

Search strategy

This systemic review and meta-analysis is carried out in accordance with criteria and recommendations of Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA). Databases used for collection of studies were PubMed, Web of Science, PEDro, CINAHL and Science Direct. Last search was performed on January 31, 2021. The keywords used were Post activation potentiation, Jump, Sprint, Speed, performance in different combinations. Duplicate publications were removed.

Eligibility criteria

Following were the inclusion criteria for this literature review: a) accessible in English; b) assessed the immediate impact of heavy squat persuade PAP on the jump and sprint execution; c) Randomized control trials; d) involved athletic population; e) using barbell back squat ≥ 80% of 1RM as a stimulus; f) recent 10 years (2010-2021).

The Exclusion criteria was as follows: a) not accessible in English; b) meta-analysis and review articles; c) did not include countermovement jump and sprint test ≤ 30m as an outcome measure; d) PAP was induced through electrical stimulation or plyometric exercise; e) subjects were non-athletes; f) using a stimulus < 80% of 1 RM; g) involved water-based sports e.g. swimming sprint; h) involved smith machine squat or yo-yo squat. 1299 studies were initially found through the databases. Studies were excluded initially based on title and abstracts and then following thorough text analysis with the help of the reviewers. A flow chart of the study selection is provided in Fig 1.

Quality assessment

Independent researchers carried out the screening as well as the inclusion and exclusion procedures for randomized control trials. Discussion and agreement among the researchers were used to settle any differences. The methodological quality was evaluated using a Pedro scale with a maximum score of 11. Studies with a score of at least 6 were included.

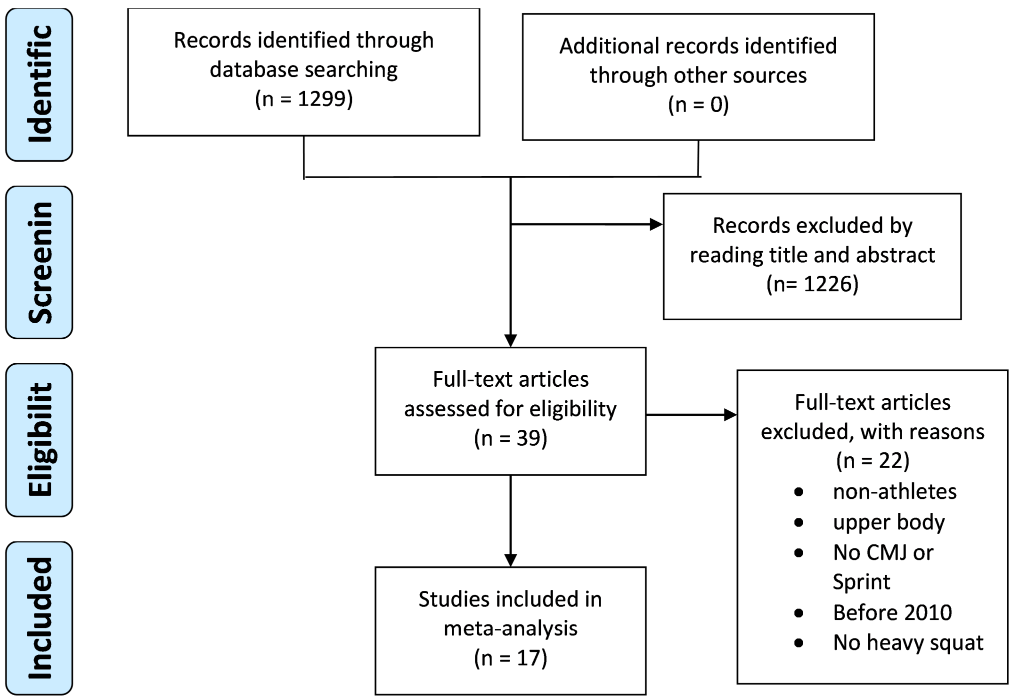


Fig. 1. PRISMA flow-diagram.

Results

Description of selected studies

1299 manuscripts were found in the databases and given to the library. 39 original papers (Fig. 1) remained after duplicates were removed and the exclusion criteria were applied to the title and abstract. 22 of the 39 original papers were taken out due to exclusion and inclusion criteria. The inclusion criteria were met by 17 publications, which were then included in meta-analyses since they provided sufficient data for quantitative evaluation. Each of the 30 publications was carefully reviewed by two reviewers before being accepted, and information from each Randomized Controlled Trial was gathered. Each paper was reviewed by two reviewers using the PEDro scale. The PEDro scale evaluation findings are displayed individually in Table 9.

Study characteristics

Among the studies included in the systematic review, the samples were composed on average by 15.2 (±5.5) individuals, ranging from 8 (Fukutani *et al.*, 2014) to 28 subjects (Sañudo *et al.*, 2020) and mean age of participants ranged from 18 ± 2 to 25.0 ± 4.8 years.

Table 1. Characteristics of Included Studies.

Study	Subjects	PAP stimulus	Rest periods	Desired outcomes	Result
Esformes & Bampouras 2013 (Esformes & Bampouras, 2013)	27 male rugby players (age, 18±2 years; body mass, 87.2±5.4 kg; height, 180.7±5.1 cm)	Parallel squat: 1X3 @3RM Quarter squat: 1X3 @3RM	5 min	CMJ height	Post CMJ height improved significantly compared to baseline (p < 0.05)
Fukutani ...et.. al., 2014 (Fukutani ..*et al.*, 2014)	8 weightlifters (age, 19.8±1.3 years; height, 1.67±0.07 m; body mass, 77.1±14.8 kg	Parallel squat High Volume: 1X5 @ 45% of 1RM 1X5 @ 60% of 1RM 1X3 @ 75% of 1RM 1X3 @ 90% of 1RM; 2 min rest b/w sets; Low volume: 1X5 @ 45% of 1RM 1X5 @ 60% of 1RM 1X3 @ 75% of 1RM; 2 min rest b/w sets	1 min	CMJ height	jump height increased significantly (p = 0.012, effect size = 0.59)
Mina *et al.*, 2018-2019 (Mina .et.. ..al., 2018-2019)	15 active men (age = 21.7 ± 1.1 year, height = 1.8 ± 0.1 m, mass = 77.6 ± 2.6 kg	Parallel squat Fixed weight: 1X3 @ 85% of 1RM; Variable resistance with bands: 1X3 @ 85% of 1RM	30s, 4min, 8min, 12min	CMJ height	no significant changes (P > 0.05) were found in jump height at any time point compared with pre-intervention data
Mitchell and Sale., 2011 (Mitchell & Sale, 2011)	11 men (age 20.5 ± 2.3 years (SD), height 178.3 ± 7.6 cm, mass 87.9 ± 8.7 kg	Parallel Squat: 5 RM; Control group: no squat	4 min	CMJ height	CMJ height increased significantly (P<0.05) 4 min after the 5-RM squat
Naclerio *et al.*, 2013 (Naclerio et.... al., 2013)	15 student athletes, male (8 American Professional football and(7 baseball) (20.3±1.3 years, height 179.50±5.3 cm, body mass 81.0 ± 10.8 kg	No Vibration-Parallel squat: 3x3 @ 80% of 1RM; Whole body vibration-Parallel squat: 3x3 @ 80% of 1RM; Control group: standing	1 min, 4 min	CMJ height	Significant improvements being evaluated for the CMJ height (p = 0.005) after 4 minutes of recovery and the LV protocol (p = 0.015)
Crewther et.... al., 2011 (Crewther et..... al., 2011)	9 male rugby players	Parallel squat: 1X3 @ 3RM	15s, 4min, 8min, 12min, 16min	CMJ height, sprint time (5m and 10m)	Significantly (p<0.001) better CMJ height at 4, 8, and 12 compared to baseline readings, but there were no temporal changes in the sprint
Petsico *et al.*, 2019 (Petisco *et al.*, 2019)	10 Professional male soccer players (age: 21.6 ± 3.2 years, body height: 177.9 ± 4.3 cm, and body mass:	Parallel squat: 1x10@60% of 1RM; Parallel squat: 1x5@80% of 1RM;	6 min	CMJ height, Sprint 30m	Possibly to most likely improvements were seen in CMJ after the 80%-1RM protocol in comparison to the 100%-1RM and 60%-1RM

Study	Subjects	PAP stimulus	Rest periods	Desired outcomes	Result
	69.5 ± 3.1 kg)	Parallel squat: 1x1@100% of 1RM; Control group: warmup			protocols. Possible better performance was achieved in the S-30 after the 80%-1RM compared to the 100%-1RM
Carbone *et al.*, 2020 (Carbone *et al.*, 2020)	17 amateur male rugby players (age 22.14 ± 2.52 years; body mass 81.06 ± 9.6 kg; height 1.78 ± 0.05 m; BMI 25.58 ± 2.59 kg·m -2	Back Squat: 3x3 @ 85% of 1RM; Hip thrust: 3x3 @ 85% of 1RM	8 min	Sprint time (5m and 10m)	no effect 5-m (P = 0.537) or 10-m (P = 0.127).
Lim and Kong, 2013 (Lim & Kong, 2013)	12 well-trained male sprinters	Dynamic Squat: 1x3 @ 90% of 1RM Isometric Squat: 3 reps of 3sec Isometric knee extension: 3 reps of 3 sec Control: 4 min rest	4 min	Sprint time (10m, 20m, 30m)	no discernible variations in sprint performance between the control, isometric knee extension, isometric squat, and dynamic squat protocols
Sharma *et al.*, 2018 (Sharma *et al.*, 2018)	14 male collegiate soccer players (age = 18.57 ± 0.94 years, height = 172.21 ± 5.07cm, and mass = 64.79 ± 7.98kg)	Parallel squat: 1x10 @ 90% of 1RM Plyometric: 2x10 Ankle hops 3x5 Hurdle hops (70cm) 5 drop jumps (50cm)	1min, 10min	CMJ height, sprint time (20m)	CMJ height was significantly better for PLY after 1min (*P*=0.004) and after 10min (*P*= 0.001) compared to that for RES No significant difference between PLY and RES after 1min (*P*= 0.155). 20-m sprint time was significantly reduced for PLY after 10min
Beato *et al.*, 2019 (Beato *et al.*, 2019)	10 male amateur athletes (age 22 ± 2 years; body mass 73.2 ± 8.0 kg; height 1.79 ± 0.05 m)	TW: half squat 3x6 @ 57.7±10.1kg EOL: half squat 3x6 @ diameter = 0.285 m; mass = 6.0 kg; moment of inertia = 0.06 kg.m 2	1min, 3min, 7min	CMJ height, sprint time (5m)	differences within (time) using EOL exercise for CMJ height, but not in 5 m sprint. Differences within (time) using TW exercise for CMJ height but not in 5 m sprint.
Sanudo et.. al., 2020 (Sañudo *et al.*, 2020)	28 male athletes, (age: 23.5 ± 5.3 years, height: 1.77 ± 0.1 m, mass: 74.3 ± 7.1 kg	Parallel squat (TRA): 1x3 @ 90% of 1RM FW (flywheel) 1x3 @ 90% of 1 RM	4min	CMJ height, sprint time (10m)	Significant changes in the 10 m sprint time were observed both with FW ($p < 0.001$) and TRA ($p = 0.025$). CMJ height was also significantly improved in FW ($p < 0.001$) and TRA ($p < 0.001$) groups.
Wyland *et al.*, 2015 (Wyland et.. al., 2015)	20.. resistance- ..trained.. males (age: 23.3 ± 4.4 years; height: 178.9 ± 6.5 cm; weight: 88.3 ± 10.8 kg)	Parallel squat(STND): 5X3 @ 85% of 1RM Variable resistance (BAND): 5x3 @ 85% of 1RM with 30% from bands Control	Immediate, 1min, 2min, 3min, 4min	Sprint time (9.1m)	no substantial adjustments in sprint time across Post testing times during the CTRL and STND condition. During the BAND condition, sprint time significantly decreased from Post-Immediate to Post-4min ($p = 0.002$)
Hester *et al.*, 2017 (Hester et.. al., 2017)	14 resistance-trained men (age = 22 ± 2.1 years, body mass = 86.29 ± 9.95 kg, and height = 175.39 ± 9.34 cm)	Back squat: 1x5 @ 80% of 1RM Jump squat: 1x10 @ 20% of 1RM	1min, 3min, 5min, 10min	CMJ height	no significant condition x time interaction for jump height ($p = 0.127$)
Bevan et... al., 2010 (Bevan et.. al., 2010)	16 professional male rugby players (age = 25.0 ± 4.8 years, body mass = 103.0 ± 12.6 kg, and height = 184.6 ± 6.3 cm)	Back squat: 1x3 @91% of 1RM	4min, 8min, 12min, 16min	Sprint time (5m and 10m)	no discernible time effect during the course of 5 m ($p = 0.175$) and 10-m sprint times ($p = 0.401$).
Piper et... al., 2020 (Piper *et al.*, 2020)	13 resistance trained, college-aged men (n = 10) and women (n = 3) (age = 20 ±2 years,	Back squat: 3x5 @87% of 1RM Plyometric (weighted	20sec, 4min, 8min, 12min, 16min, 20min	CMJ height, sprint time (20m)	Significantly faster 20m sprint times ($p < .05$) at the 4, 8, 12, 16, and 20-minute time points compared to baseline.

Study	Subjects	PAP stimulus	Rest periods	Desired outcomes	Result
	body mass = 74.7 ± 13.3 kg, and height = 175 ± 9 cm)	jump): 3x5 @ max voluntary + 10% body weight Isometric (30° back squat): 3 x 3sec Control: Walk 4min			Significantly faster 20m sprint times (p < .05) were also shown for the squat intervention compared to control at 4-minutes, the plyometric and squat intervention compared to control at 8-minutes, the isometric intervention compared to control at 12 and 16 minutes, and the isometric intervention compared to the squat at 20-minutes.
Scott *et al.*, 2018 (Scott *et al.*, 2018)	20 rugby league players (age: 22.35.. ± 2.68 ..years; height: 182.23 ± 6.00 cm; mass: 94.79 ± 12.79 kg)	Back squat: 1x3 @70% of 1RM + 0-23% 1RM from elastic band Hex-bar deadlift: 1x3 @70% of 1RM + 0-23% 1RM from elastic band Control: 5min walk	30s, 90s, and 180s	CMJ height	no significant (p> 0.05) PAP for either of the exercise conditions compared to baseline no significant (p>0.05) variations in exercising circumstances

Endpoints

Countermovement Jump (time dependent relation)

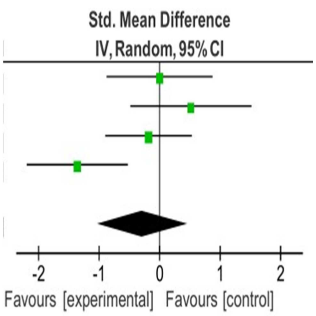
After 1 minute

4 (Beato *et al.*, 2019; Fukutani *et al.*, 2014; Naclerio *et al.*, 2013; Sharma *et al.*, 2018) out of 17 included Randomized Controlled Trials have studied the effect of PAP using back squat on the countermovement jump height at 1 minute after PAP stimulus. After meta-analysis there is no significant effect on countermovement jump height at 1minute after the PAP stimulus, SMD = -0.28 (95% CI = -1.03, 0.47); p = 0.46; I² = 68% (Table 2).

Table 2. Countermovement jump measured 1 minute after PAP stimulus.

	Experimental			Control				
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Beato *et al.*, 2019	34	1.4	10	34	1.4	10	24.6%	0.00 [-0.88, 0.88]
Fukutani *et al.*, 2014	51	8	8	46.5	8.5	8	22.3%	0.52 [-0.49, 1.52]
Naclerio *et al.*, 2013	35.7	4.1	15	36.5	4.4	15	27.7%	-0.18 [-0.90, 0.53]
Sharma *et al.*, 2018	28.04	3.24	14	32.68	14	25.4%		-1.36 [-2.20, -0.53]
Total (95% CI)			47			47	100.0%	-0.28 [-1.03, 0.47]

Heterogeneity: Tau² = 0.39; Chi² = 9.30, df = 3 (P = 0.03); I² = 68%
Test for overall effect: Z = 0.74 (P = 0.46)



After 4 minutes

5 (Crewther *et al.*, 2011; Mina *et al.*, 2018; Mitchell & Sale, 2011; Naclerio *et al.*, 2013; Sañudo *et al.*, 2020) out of 17 included Randomized Controlled Trials studied the effect of PAP using back squat on the countermovement jump height at 4 minutes after PAP stimulus. After meta-analysis there was no significant effect of PAP stimulus on the countermovement jump height at 4 minutes after PAP stimulus, SMD = 0.41(95% CI = -1.14, 1.96); p = 0.60; I² = 93% (Table 3).

After 8 minutes

2 (Crewther *et al.*, 2011; Mina *et al.*, 2018) out of 17 included Randomized Controlled Trials studied the effect of PAP using back squat on the countermovement jump height at 8 minutes after PAP stimulus.

After meta-analysis there was no significant effect of PAP on the countermovement jump height at 8 minutes after PAP stimulus, SMD = 0.24 (95% CI = -0.33,0.81); P = 0.40; I² = 0% (Table 4).

Table 3. Countermovement jump measured 4 minutes after PAP stimulus.

Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Crewther *et al.*, 2011	49	6	9	48	6	9	24.3%	0.16[-0.77, 1.08]
Mina *et al.*, 2018	375	1.5	15	36	1.5	15	0.1%	219.89[160.19, 279.59]
Mitchell and Sale., 2020	49.5	1.8	11	48	1.9	11	24.6%	0.78[-0.09, 1.65]
Naclerio *et al.*, 2013	36.5	4.3	15	36.8	3.8	15	25.2%	-0.07[-0.79, 0.64]
Sanudo *et al.*, 2020	36	5	28	35	5	28	25.8%	0.20[-0.33, 0.72]
Total(95%CI)			78			78	100.0%	0.41[-1.14, 1.96]

Heterogeneity: $Tau^2 = 2.35$; $Chi^2 = 54.25$, df = 4 ($P < 0.00001$); $I^2 = 93\%$
Test for overall effect: Z = 0.52 (P = 0.60)

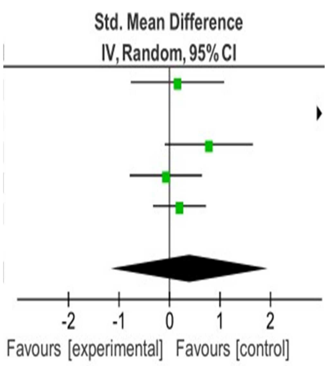
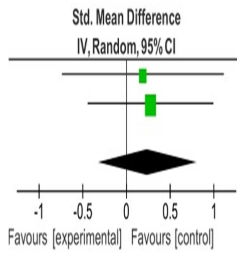


Table 4. Countermovement jump measured 8 minutes after PAP stimulus.

Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Crewther *et al.*, 2011	49	4	9	48	6	9	37.6%	0.19 [-0.74, 1.11]
Mina *et al.*, 2018	36.5	2	15	36	1.5	15	62.4%	0.28 [-0.44, 0.99]
Total (95% CI)			24			24	100%	0.24 [-0.33, 0.81]

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.02$, df = 1 (P = 0.88); $I^2 = 0\%$
Test for overall effect: Z = 0.83 (P = 0.40)



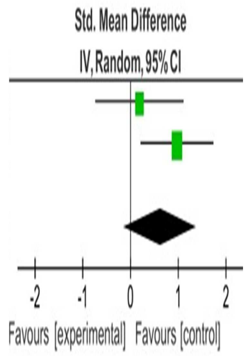
After 12 minutes

2 (Crewther *et al.*, 2011; Mina *et al.*, 2018) out of 17 included Randomized Controlled Trials studied the effect of PAP using back squat on the countermovement jump height at 12 minutes after PAP stimulus. After meta-analysis there was no significant effect of PAP on the countermovement jump height at 12 minutes after PAP stimulus, SMD = 0.63 (95% CI = -0.14, 1.39); P = 0.11; I^2 = 39% (Table 5).

Table 5. Countermovement jump measured 12 minutes after PAP stimulus.

Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Crewther *et al.*, 2011	49	4	9	48	6	9	44.2%	0.19 [-0.74, 1.11]
Mina *et al.*, 2018	37.5	1.5	15	36	1.5	15	55.8%	0.97 [-0.21, 1.74]
Total (95% CI)			24			24	100%	0.63 [-0.14, 1.39]

Heterogeneity: $Tau^2 = 0.12$; $Chi^2 = 1.65$, df = 1 (P = 0.20); $I^2 = 39\%$
Test for overall effect: Z = 1.60 (P = 0.11)



5-m sprint (time dependent relation)

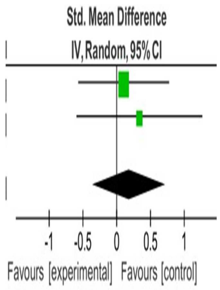
After 8 minutes

2 (Carbone *et al.*, 2020; Crewther *et al.*, 2011) out of 17 included Randomized Controlled Trials studied the effect of PAP using back squat on the 5-m Sprint at 8 minutes after PAP stimulus. After meta-analysis there was no significant effect of PAP on the 5-m Sprint time at 8 minutes after PAP stimulus, SMD = 0.18 (95% CI = -0.36, 0.73); p = 0.51; I^2 = 0% (Table 6).

Table 6. 5-m sprint measured 8 minutes after PAP stimulus.

	Experimental			Control				
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Carbone *et al.*, 2020	1.09	0.09	17	1.08	0.1	17	65.8%	0.10 [-0.57, 0.78
Crewther *et al.*, 2011	1.22	0.08	9	1.19	0.09	9	34.2%	0.34 [-0.60, 1.27]
Total (95% CI)			26			26	100%	0.18 [-0.36, 0.73]

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.16$, df = 1 (P = 0.69); $I^2 = 0\%$
Test for overall effect: Z = 0.66 (P = 0.51)



10-m sprint (time dependent relation)

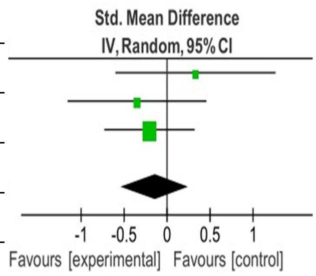
After 4 minutes

3 (Crewther *et al.*, 2011; Lim & Kong, 2013; Sañudo *et al.*, 2020) out of 17 included Randomized Controlled Trials studied the effect of PAP using back squat on the 10-m Sprint at 4 minutes after PAP stimulus. After meta-analysis there was no significant effect of PAP on the 10-m Sprint time at 4 minutes after PAP stimulus, SMD = -0.24 (95% CI = -0.54, 0.26); p = 0.49; $I^2 = 0\%$ (Table 7).

Table 7. 10-m sprint measured 4 minutes after PAP stimulus.

	Experimental			Control				
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Crewther *et al.*, 2011	1.96	0.1	9	1.93	0.07	9	18.2%	0.33 [-0.60, 1.26]
Lim and kong., 2013	1.75	0.05	12	1.77	0.06	12	24.3%	-0.35 [-1.16, 0.46]
Sanudo *et al.*, 2020	1.87	0.14	28	1.9	0.15	28	57.4%	-0.20 [-0.73, 0.32]
Total (95% CI)			49			49	100%	0.14 [-0.54, 0.26]

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 1.30$, df = 2 (P = 0.52); $I^2 = 0\%$
Test for overall effect: Z = 0.70 (P = 0.49)



After 8 minutes

2 (Carbone *et al.*, 2020; Crewther *et al.*, 2011) out of 17 included Randomized Controlled Trials studied the effect of PAP using back squat on the 10-m at 8 minutes after PAP stimulus. After meta-analysis there was no significant effect of PAP on the 10-m Sprint time at 8 minutes after PAP stimulus, SMD = 0.26 (95% CI = -0.28, 0.81); p = 0.34; $I^2 = 0\%$ (Table 8).

Table 8. 10-m sprint measured 8 minutes after PAP stimulus.

	Experimental			Control				
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Carbone *et al.*, 2020	1.88	0.19	17	1.84	0.17	17	65.7%	0.22 [-0.46, 0.89]
Crewther *et al.*, 2011	1.96	0.09	9	1.93	0.07	9	34.3%	0.35 [-0.58, 1.29]
Total (95% CI)			26			26	100%	0.26 [-0.28, 0.81]

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.05$, df = 1 (P = 0.81); $I^2 = 0\%$
Test for overall effect: Z = 0.95 (P = 0.34)

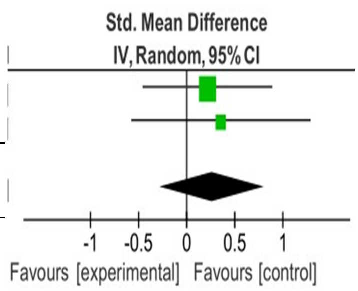


Table 9. Quality assessment.

Studies	1	2	3	4	5	6	7	8	9	10	11	Total
Esformes & Bampouras 2013 (Esformes & Bampouras, 2013)	1	1	0	1	0	0	0		1	1	1	7
Fukutani *et al.*, 2014 (Fukutani *et al.*, 2014)	1	1	0	1	0	0	0	1	1	1	1	7
Mina *et al.*, 2018 (Mina *et al.*, 2018)	1	1	0	1	0	0	0	1	1	1	1	7
Mitchell *et al.*, 2011 (Mitchell & Sale, 2011)	1	1	0	1	0	0	0	1	1	1	1	7
Naclerio *et al.*, 2013 (Naclerio *et al.*, 2013)	1	1	0	0	0	0	0	1	1	1	1	6
Hester *et al.*, 2017 (Hester *et al.*, 2017)	1	1	0	1	0	0	0	1	1	1	1	7
Bevan *et al.*, 2010 (Bevan *et al.*, 2010)	1	0	0	1	0	0	0	1	1	1	1	6
Crewther *et al.*, 2011 (Crewther *et al.*, 2011)	1	1	0	1	0	0	0	1	1	1	1	7
Petisco *et al.*, 2019 (Petisco *et al.*, 2019)	1	1	0	0	0	0	0	1	1	1	1	6
Carbone *et al.*, 2020 (Carbone *et al.*, 2020)	1	1	0	1	0	0	0	1	1	1	1	7
Lim & Kong 2013 (Lim & Kong, 2013)	1	1	0	1	0	0	0	1	1	1	1	7
Sharma *et al.*, 2018 (Sharma *et al.*, 2018)	1	1	0	1	0	0	0	1	1	1	1	7
Beato *et al.*, 2019 (Beato *et al.*, 2019)	1	1	0	1	0	0	0	1	1	1	1	7
Scott *et al.*, 2018 (Scott *et al.*, 2018)	1	1	0	1	0	0	0	1	1	1	1	7
Piper *et al.*, 2020 (Piper *et al.*, 2020)	1	1	0	1	0	0	0	1	1	1	1	7
Sanudo *et al.*, 2020 (Sañudo *et al.*, 2020)	1	1	0	1	0	0	0	1	1	1	1	7
Wyland *et al.*, 2015 (Wyland *et al.*, 2015)	1	1	0	0	0	0	0	1	1	1	1	6

Discussion

As the goal of this meta-analysis to define effect of strong back squat induced Post activation potentiation on recommitting jump height and sprint performance of athletes and to define the optimal rest periods after PAP stimulus for maximum performance enhancement.

The study's findings indicate that post-activation potentiation has no discernible impact on athletes' ability to jump and sprint. However, there are inconsistent findings in the current literature regarding the effect of PAP on jump and sprint performance. For instance, Pearson and Hussain (Pearson & Hussain, 2014) showed decreased jump height, peak power and rate of force development in a countermovement jump after back squat as a PAP stimulus. Conversely, there was an improvement in jump height and peak power after back squat induced PAP (Kilduff *et al.*, 2011).

Regarding the sprint performance, 5-m and 10-m sprint time were not improved after back squat induced PAP (Crewther *et al.*, 2011). In this meta-analysis Post activation activation of stimulatory effects by strong back squat (> 80% of 1RM) does not significantly improve jump performance measured as countermovement jump, and sprint performance measured as 5-m and 10-m sprint time. The effect of jump height was investigated at 1 minute, 4 minutes, 8 minutes and 12 minutes following PAP protocol. The effect on 5-m sprint time was investigated at 8 minutes following PAP protocol. The effect on 10-m sprint time was investigated at 4 minutes and 8 minutes following PAP protocol. Previous meta-analyses showed that rest intervals as well as mode of exercise, number of sets and athletes training status are moderators of the PAP, but the correlation of multiple effects is still unknown (Gouvêa *et al.*, 2013; Lesinski *et al.*, 2013; Seitz & Haff, 2016; Wilson *et al.*, 2013).

Gouvea *et al* (Gouvêa *et al.* (2013) also showed in their meta-analysis that vertical jump height does not improve significantly after a rest interval of 4–7 minutes in response to PAP persuaded using heavy back squats (> 80% of 1RM), which is similar to the present study as there was no significant improvement of countermovement jump height after a rest interval of 4 min; however, Gouvea *et al* (Gouvêa *et al.* (2013) found that there is significant improvement in jump height after 8–12 minute rest periods, It defies the findings of the present study because the jump did not substantially improve. height at 8 minutes as well as 12 minutes after the PAP stimulus. Wilson *et al* (Wilson *et al.*, 2013) showed that longer rest periods of 7-10 minutes results in maximum improvement in jump height. Seitz and Haff (Seitz & Haff, 2016) reported 5-7 minutes is the optimal rest period to achieve the maximum improvement in jump height. These results contradict this current study. The reason for improvement after longer rest periods in the above studies (Seitz & Haff, 2016; Wilson *et al.*, 2013) could be untrained subjects require more time to dissipate the fatigue which is caused by heavy squat condition activity (Short & Sedlock, 1997). Training status has been one of the important moderators of PAP. More elite athletes shows more performance enhancement as compared to recreationally active individuals (Chiu *et al.*, 2003). The disparity in outcomes could be explained by the fact that the current study only included heavy squat (> 80% of 1RM) which induces more fatigue. Moderate intensity squats with multiple sets could result in less fatigue and more performance enhancement as seen in a study by Wilson *et al* (Wilson *et al.*, 2013) , they used multiple sets with moderate intensity (60-80% of 1RM).

It appears that PAP effects are relatively minimal based on recent scientific literature and the present meta-analysis, although the interpretation of this conclusion should be used with caution as it seems that individual PAP responses may differ. The PAP response is exceptionally personalized and indicative of reporter vs. non-reporter behavior, according to a careful review of the scientific literature. Careful inspection of the literature indicates that PAP effectiveness is highly individualized in nature. This can be explained by the fact that performance enhancement after a condition activity is mediated by the net interaction of fatigue and potentiation which co-exist (Rassier & MacIntosh, 2000). If the excitability influenced by fatigue, performance will be decreased. If fatigue and potentiation are equal, performance remains unchanged, and increases if potentiation dominates fatigue (Tillin & Bishop, 2009). Therefore, with shorter rest intervals fatigue is more and reduces the effect of PAP and with longer rest intervals, fatigue dissipates and allow for greater PAP effects after the conditioning activity.

The rest interval also depends on the type of conditioning activity. For instance, greater PAP effects are observed after 0.3 to 4 min following a plyometric conditioning activity and atleast 5 minutes following a traditional high and moderate intensity conditioning activity (Tobin & Delahunt, 2014).

However, there are several limitations to the current analysis. Only trained athletes were included in the study, so results could not be generalized over general population. In addition, there were very few studies for comparing the data more studies are needed. Furthermore, the optimal volume and dosage of back squat is not taken into account for this meta-analysis.

Conclusion

The result of this meta-analysis indicates, there is no significant improvement in countermovement jump height and 5-m and 10-m sprint time after heavy back squat induced post activation potentiation. Moreover, more research is required to consider the other PAP variables, such as reps and sets, intensity, and exercise type. The effects of PAP are mostly dependent on the athlete's strength level, exercise intensity, rest interval, and type of activity.

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