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Comparison of Post-Activation Potentiating Stimuli on Jump and Sprint Performance

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ABSTRACT

International Journal of Exercise Science 13(4): 539-553, 2020. Post-activation potentiation (PAP) is a phenomenon characterized by improved muscle performance based on the previous contractile activity of the muscle. The purpose of this study was to determine the effect of different potentiating stimuli on jump and sprint performance in 13 resistance trained, college-aged men and women. After determining back squat 1 repetition max, subjects returned for testing on separate days to complete one of four interventions (dynamic resistance, weighted plyometric, isometric, or control) in a randomized order. A standardized warmup was performed, followed by a baseline countermovement jump (CMJ) and 20m sprint. Following warm-up and baseline measurements, subjects performed one of the four experimental conditions. CMJ and 20m sprint measurements were completed again at 20-seconds, 4, 8, 12, 16, and 20-minutes. Results revealed significantly faster 0-20m sprint times ($p < .05$) at the 4, 8, 12, 16, and 20-minute time points compared to baseline and 20-second time points. Significantly faster 0-20m 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. These findings indicate that while all PAP stimuli utilized can be effective at improving sprint performance, specific optimal time points may exist.

KEY WORDS: Speed, track, power, potentiation, acceleration

INTRODUCTION

Warmup sessions prior to training and competition are designed to prepare athletes for optimal performance (3). An induction of post-activation potentiation (PAP) is one desirable benefit to the warmup (23). PAP is a phenomenon characterized by enhanced muscle performance based on the previous contractile history of the muscle (9). Increased muscle contraction speeds and force production are benefits of PAP (7). Various potentiating stimuli have been used in athletics to promote force and peak power output, including traditional dynamic resistance training (9, 21), maximum voluntary isometric contractions (10, 17), and plyometric exercise (20).
Three physiological mechanisms, 1) the phosphorylation of myosin regulatory light chains, 2) increases in motor unit recruitment, and 3) changes in pennation angle have been proposed to

explain PAP (19). With the phosphorylation of myosin regulatory light chains, actin and myosin are believed to be more sensitive to calcium released from the sarcoplasmic reticulum resulting in an increase in the rate of cross-bridging (7). In regards to motor unit recruitment, it is thought that the stimulation of neural fibers which activate alpha motor neurons results in an increase in post-synaptic potentials for the same pre-synaptic potential during activity following stimulation (19).

Contrary to this, temporary fatigue is a potential disadvantage of the intended potentiation stimulus, and therefore research has been done to assess the optimal time PAP stimuli should be performed prior to explosive, anaerobic activities. There is some consensus that the PAP stimulus should be performed ~4-12 minutes prior to the subsequent anaerobic activity (9, 21). However, there is a lack of research comparing different potentiating stimuli. This is particularly important in a competition or field setting where some PAP stimuli may be more feasible to perform than others, such as plyometrics compared to traditional resistance training.

Traditional dynamic resistance training, generally performed with compound lifts such as back squat, bench press, and deadlift, has been previously utilized as a potentiating stimuli. In a meta-analysis conducted by Wilson, et al. (21), moderate intensities, 60-84% of the 1-repetition maximum (1RM), and multiple sets optimized potentiation better than heavy intensities, > 85%1RM, and single sets. However, Kilduff, et al. (9) showed significant increases in peak power and CMJ height 8-minutes following 3 sets of 3 repetitions on back squat at ≥ 80%1RM.

Plyometric exercise is a type of explosive movement that can be performed using an athlete’s body weight, without bulky equipment. Plyometric exercise leads to the recruitment of more motor units by utilizing the stretch-shortening cycle, leading to an increase in power (14). Previously, both weighted and unweighted alternating-leg bounding improved sprint acceleration. However, performing the plyometrics with a weighted vest (10% body weight) resulted in greater improvements (20).

Maximum voluntary isometric contractions have also been studied as a potential PAP stimulus. Kovačević, et al. (10) investigated acute effects of maximal isometric contractions on explosive power. Maximal isometric semi-squat contractions held for 6-seconds resulted in significant increases in vertical jump 60- and 90-seconds post, demonstrating that isometric PAP protocols are also effective in enhancing power abilities.

While some PAP techniques may be more feasible and allow for easier utilization in field settings vs. laboratory settings, it is still unclear if one particular PAP stimulus is more effective as there is limited research comparing the different stimuli (11). Additionally, the timing after the PAP stimulus is important in regards to the impact on performance. However, it remains unclear if the time course for PAP benefits varies based on methods used. Therefore, the purpose of this study was to determine the effect of different PAP stimuli (dynamic resistance, weighted plyometric, isometric, control) on countermovement jump height and 20m sprint speed in resistance trained, college-aged men and women. A secondary purpose was to determine if the time course for optimal performance following the PAP stimulus differs across different modalities.

METHODS

Participants

Thirteen resistance trained, college-aged men (n = 10) and women (n = 3) completed the study. Subject demographics can be seen in Table 1. Inclusion criteria required a back squat 1RM of greater than 1.7 times body weight and resistance training status of 3 days per week for 4 months. A well-trained population was utilized, as stronger and more conditioned subjects have a greater response to potentiating stimuli (6). This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (13). All procedures were approved by the Institutional Review Board prior to the start of the study and subjects provided informed consent before beginning testing. Sample size estimates (G*Power 3.1.9.2) determined that for a mean difference in sprint times of .05 seconds and SD of difference of .05 seconds (effect size = 1), at least 9 subjects would be needed to achieve power of 0.8 with an α of 0.05.

Protocol

Testing for an individual subject was conducted on 5 separate days. A minimum of 48-hours was given between testing days for complete recovery. The following were confirmed by a pre-test checklist prior to each session: 1) no exercise within 24 hours, 2) no large meal within 2 hours, 3) no caffeine/pre-workout within 12 hours, and 4) subject indication of adequate recovery. On the first day, subjects reported to the testing site for measurements of height, weight, body fat percentage (DEXA, GE Prodigy, Chicago, IL), back squat 1 repetition max testing, and familiarization of the PAP stimuli. On the other 4 testing days, subjects performed, in a randomized order, 1 of 3 different PAP stimuli (dynamic resistance, plyometric, isometric) or a control session. On each testing day, a standardized warm-up (Table 2) was completed, followed by baseline testing of a CMJ and 20-meter sprint. After baseline testing, subjects completed 1 of the 3 PAP stimuli or control. Twenty seconds after the assigned stimulus or control, and 4-, 8-, 12-, 16-, and 20-minutes post, subjects repeated the CMJ and 20m sprint testing following the same procedures as baseline.

Table1. Demographic values of resistance trained men and women.

Variables	Men (n = 10)	Women (n = 3)	Total (n = 13)
Age (years)	21 ± 2	20 ± 1	20 ± 2
Weight (kg)	79.6 ± 11.0	58.5 ± 1.4	74.7 ± 13.3
Height (cm)	178 ± 7	163 ± 7	175 ± 9
BMI (kg/m^2)	25.0 ± 2.6	22.0 ± 1.6	24.3 ± 2.7
Body Fat (%)	15.0 ± 4.3	23.4 ± 4.5	17.0 ± 5.5
Squat 1RM (kg)	155 ± 26	108 ± 11	144 ± 31
Squat 1RM% (%BW)	1.94 ± 0.16	1.85 ± 0.15	1.92 ± 0.16
Training Frequency (days/week)	5.1 ± 0.88	4.7 ± 0.88	5.0 ± 1.0

Note. All values represent mean ± SD.

Table 2. Standardized warmup routine performed before each trial.

Exercise	Sets/Reps
400m Jog	1x400m
Walking Knee Hugs w/Twist	2x5 each
Walking Toe Touches	2x5 each
Static Calf Stretch	2x20s each
Forward Lunges	2x5 each
Walking Quad Pulls	2x5 each
Glute Bridge	2x10
Body Weight Squat	1x10

Three PAP stimuli (dynamic resistance, plyometric, isometric) were used for this study in addition to a control trial. The exercise prescription (mode, sets, reps, intensity, etc.) for each PAP stimulus is displayed in Table 3. Weighted plyometrics were chosen over unweighted plyometrics as previous studies have shown that weighted plyometrics elicit a better PAP response (1). Subjects were positioned into a squat position of 30˚ to perform this isometric back squat (Figure 1). The position (4) and amount of sets and seconds utilized (5, 15) was based on past research. For the control session, subjects did not perform any PAP stimulus. Instead, subjects performed a 4-minute walk after the standardized warmup and then performed the post-testing.

Countermovement jump height was measured using the Just Jump mat (Probotics Inc., Huntsville, AL). Subjects were instructed to perform the CMJ by starting with their arms up and dropping down to a squat position as quickly as possible, loading the arms behind the body. After exploding into the jump, subjects were instructed to land on the mat with their legs straight. All subjects underwent familiarization of testing procedures at the initial visit to ensure proper technique. CMJ height was measured at baseline and at 20 seconds and 4-, 8-, 12-, 16-, and 20-minutes following each intervention.

Table 3. Post-activation potentiating stimuli techniques

PAP Stimulus	Exercise	Intensity	Reps/Duration	Sets	Rest
Dynamic Resistance	Back Squat	87% 1RM	5 reps	3	3 min
Plyometric	Weighted Jump	max voluntary +10% body weight	5 reps	3	3 min
Isometric	30˚Back Squat	max voluntary	3 sec	3	3 min
Control	Walk	N/A	4 min	1	N/A

Figure 1. Image of isometric back squat device.

Sprint times were measured using automatic timing gates (Brower Timing TC-System, Draper, UT) placed at 0-, 10-, and 20m. Timing gates were set at a height of 105 cm. Immediately (~5-10 seconds to allow time to get set for the sprint) following the CMJ, subjects performed a 20m sprint to measure acceleration speed. Subjects were instructed to start one-half meter behind the timing gates placed at the 0-meter mark. Subjects were in a split stance starting position prior to starting the sprint. Times from distances of 0 to 10m, 10m to 20m, and 0 to 20m were used for data collection. Sprint times were measured at each time point (baseline, 20 seconds post, 4-, 8-, 12-, 16-, and 20-minutes post).

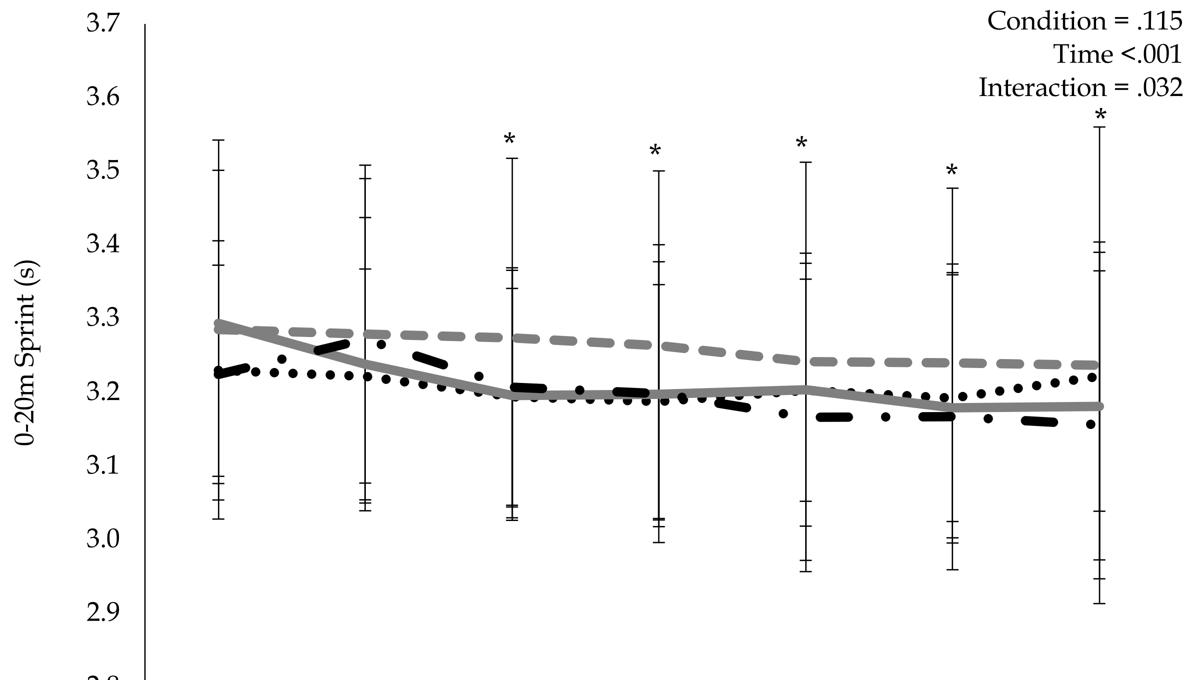
Statistical Analysis

A 2-way (condition x time) repeated measures ANOVA was used for statistical analysis. Using the mean values for each dependent variable (CMJ, 0-10m time, 10-20m time, and 0-20m time), main effects for condition (dynamic resistance, plyometric, isometric, control) and time (baseline, 20s post, 4, 8, 12, 16, and 20min post) were determined, as well as any condition x time interaction. Significant main effects were followed up with pairwise comparison (least significant differences). Interactions were followed up with one-way ANOVA. All statistical analyses were performed in SPSS. Intraclass correlation coefficients (two-way mixed, absolute agreement, single measures) for each dependent variable measured were as follows: 0-20m time (.753), 0-10m time (.747), 10-20m time (.623), CMJ (.820).

RESULTS

Mean values from baseline to 20-minutes post intervention for 0-20m sprint times are shown in Figure 2. A main effect for time ($p \leq .001$) and interaction ($p = .032$) was shown, but no main effect for condition. Pairwise comparisons for time showed significantly faster 0-20m sprint times at 4, 8, 12, 16, and 20-minutes post-intervention compared to baseline and 20-seconds post-intervention. There were also significantly faster 0-20m sprint times at 16-minutes post-intervention compared to 4-minutes. For the interaction, repeated one-way ANOVA were run to compare conditions at a given time point. Comparisons revealed significantly faster 0-20m sprint time ($p < .05$) for the squat intervention compared to the control at 4-minutes. The plyometric ($p = .060$) and isometric ($p = .055$) interventions trended towards significant differences compared to control at the 4-minute time point. Also, the plyometric and squat intervention were significantly faster ($p < .05$) at the 8-minute time point compared to the control. The isometric intervention trended toward significant difference ($p = .068$) compared to control at the 8-minute time point. At the 12 and 16-minute time points, the isometric intervention was significantly faster ($p < .05$) than the control. Also, the isometric intervention was significantly faster ($p < .05$) than the squat intervention at the 20-minute time point. Observed power for the 0-20m overall repeated measures analysis was as follows: condition (.496), time (1.0), and interaction (.95).

Mean values from baseline to 20-minutes post intervention for 0-10m split times are shown in Figure 3. A main effect for time ($p \leq .001$) was shown, but there was no main effect for condition or interaction. Pairwise comparisons for time showed faster 0-10m split times at 4, 8, 12, 16, and 20-minutes compared to baseline. Also, significantly faster 0-10m split times occurred at 8, 12, 16, and 20-minutes post-intervention compared to 20-seconds post-intervention. Observed power for the 0-10m overall repeated measures analysis was as follows: condition (.553), time (.996), and interaction (.881).

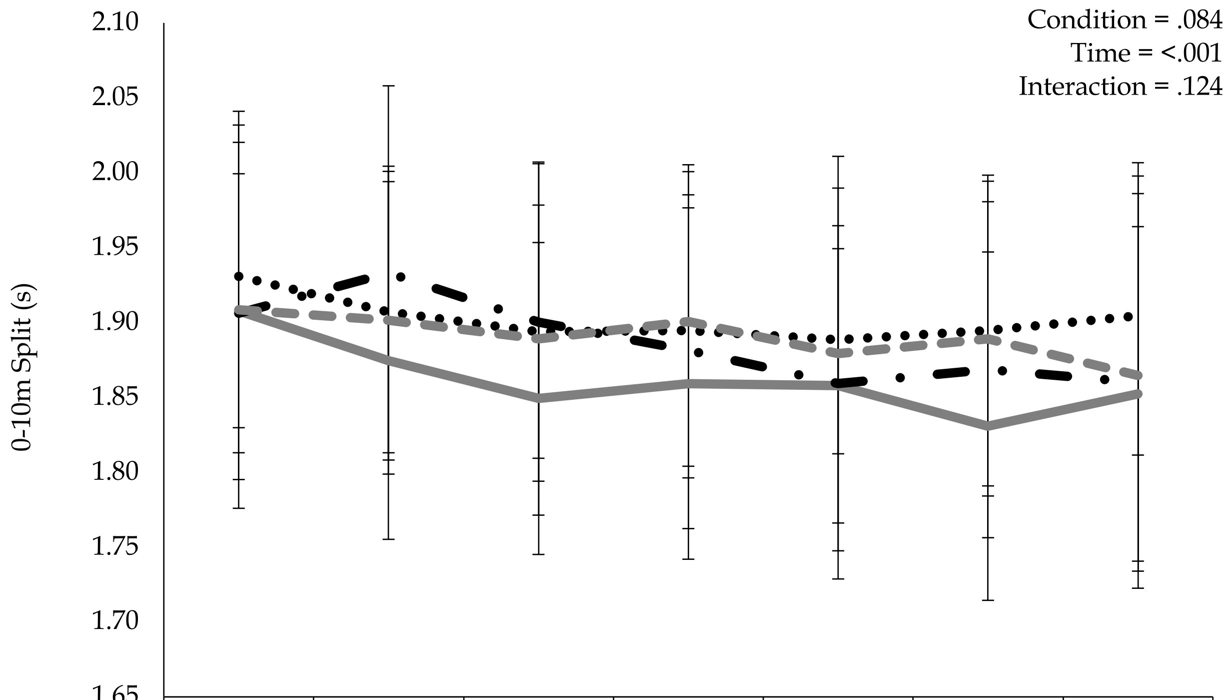


	Baseline	20s	4min	8min	12min	16min	20min
Squat	3.23	3.22	3.19 †	3.19 †	3.20	3.19	3.22
Plyo	3.29	3.24	3.20	3.20 †	3.20	3.18	3.18
Iso	3.22	3.27	3.21	3.20	3.17 †	3.17 †	3.16 ǂ
Control	3.29	3.28	3.27	3.26	3.24	3.24	3.24

Time Point

Figure 2. 0-20m split time (s) at baseline, 20 seconds, 4, 6, 8, 12, 16, and 20 minutes post intervention for squat, plyometric, isometric, and control sessions. *Significant difference, $p < .05$, across conditions at the same time point. † = significant difference, $p < .05$, compared to control at the same time point. ǂ = significant difference, $p < .05$, compared to squat at the same time point.

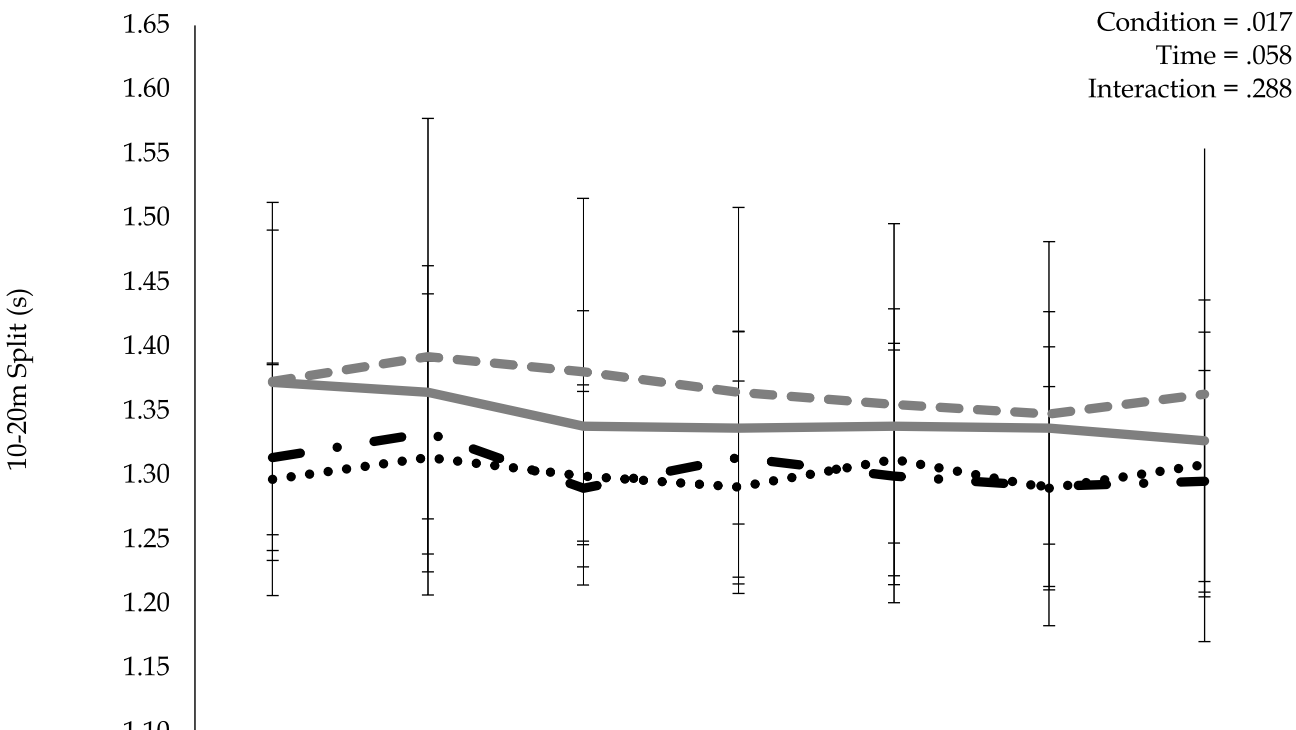
For 10-20m split times, mean values from baseline to 20-minutes post are shown in Figure 4. Significance values were adjusted (Greenhouse-Geisser) for this analysis as Mauchly's test of sphericity was not met. There was a main effect for condition (p = .017) and a trend for a main effect for time (p = .058), but no interaction. Pairwise comparisons for condition showed squat and isometric were significantly faster than plyometric and control. Pairwise comparisons for time showed a significantly faster 10-20m split at 4, 8, 12, and 16-minutres post compared to 20-seconds post-intervention. Observed power for the 10-20m overall repeated measures analysis was as follows: condition (.924), time (.869), and interaction (.838).



	Baseline	20s	4min	8min	12min	16min	20min
Squat	1.93	1.91	1.89	1.89	1.89	1.89	1.90
Plyo	1.91	1.87	1.85	1.86	1.86	1.83	1.85
Iso	1.91	1.93	1.90	1.88	1.86	1.87	1.86
Control	1.91	1.90	1.89	1.90	1.88	1.89	1.86

Time Point

Figure 3. 0-10m split time (s) at baseline, 20 seconds, 4, 6, 8, 12, 16, and 20 minutes post intervention for squat, plyometric, isometric, and control sessions.

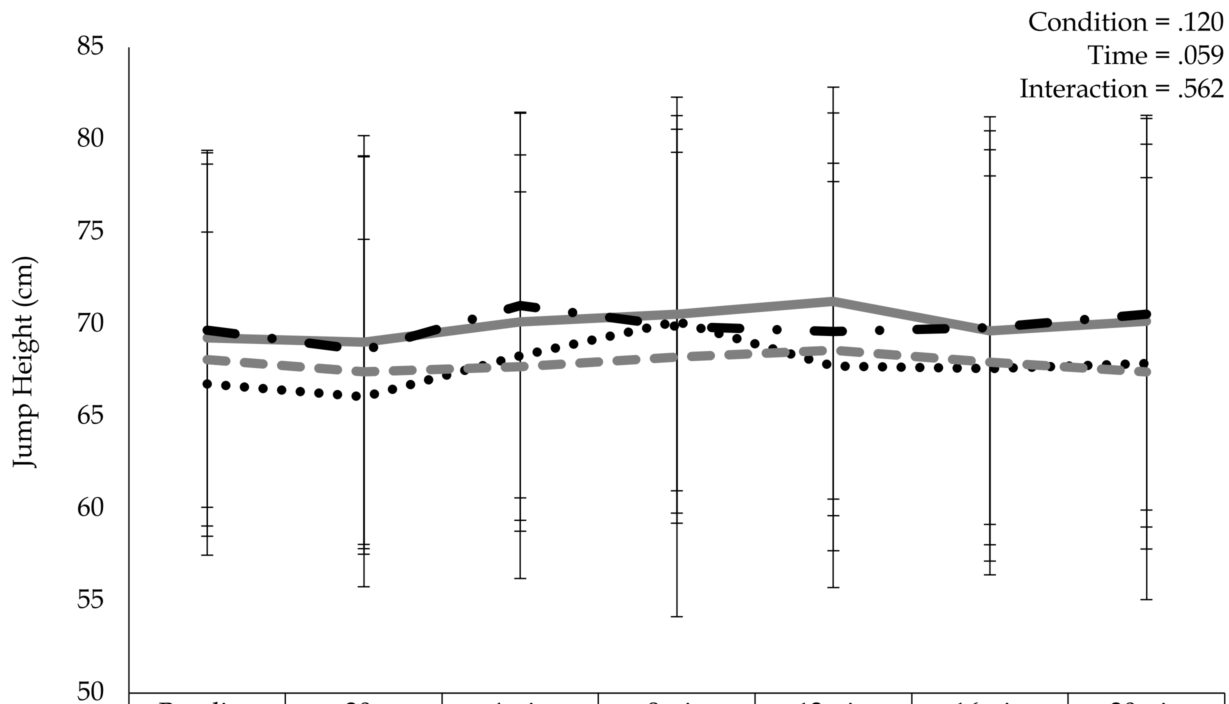


	Baseline	20s	4min	8min	12min	16min	20min
Squat	1.30	1.31	1.30	1.29	1.31	1.29	1.31
Plyo	1.37	1.36	1.34	1.34	1.34	1.34	1.33
Iso	1.31	1.33	1.29	1.31	1.30	1.29	1.30
Control	1.37	1.39	1.38	1.36	1.36	1.35	1.36

Time Point

Figure 4. 10-20m split time (s) at baseline, 20 seconds, 4, 6, 8, 12, 16, and 20 minutes post intervention for squat, plyometric, isometric, and control sessions.

For CMJ height, mean values from baseline to 20-minutes post are displayed for each condition in Figure 5. Significance values were adjusted (Greenhouse-Geisser) for this analysis as Mauchly's test of sphericity was not met. There was a trend for a main effect for time (p = .059), but no main effect for condition or interaction. Pairwise comparisons for time revealed significantly greater CMJ heights at 8-minutes compared to baseline, and at 4 and 8-minutes compared to 20-seconds post. Observed power for the CMJ overall repeated measures analysis was as follows: condition (.539), time (.847), and interaction (.574).



	Baseline	20s	4min	8min	12min	16min	20min
Squat	66.7	66.1	68.3	70.1	67.7	67.6	67.9
Plyo	69.2	69.0	70.1	70.5	71.2	69.6	70.2
Iso	69.7	68.6	71.0	69.9	69.6	69.8	70.5
Cont	68.1	67.4	67.7	68.2	68.6	67.9	67.4

Figure 5. CMJ height (cm) at baseline, 20 seconds, 4, 6, 8, 12, 16, and 20 minutes post intervention for squat, plyometric, isometric, and control sessions.

Summary data showing the change in sprint times and CMJ height following each intervention relative to baseline and adjusted to the control session are displayed in Table 4. For each condition, first the change from each time point post intervention relative to baseline for that intervention was calculated (post-baseline). The same was done for the control intervention. Then the difference between the change at a given time point for each intervention relative to control was calculated (Δ condition - Δ control). For example, if a subject improved from 3.0s to 2.9s (Δ -.1s) at a given time point for a particular intervention, and the same subject improved from 3.1s to 3.05s (Δ -.05s) for the control trial at the same time point, then the change adjusted to control would be .05s (-.1s – -.05s).

Table 4. Δ (post-pre) in sprint time and CMJ adjusted to control (Δ condition-Δ control)

		Time Point					
Variable	Condition	20s	4 min	8 min	12 min	16 min	20 min
0-20m Sprint (s)	Squat	0.00 ± 0.08	-0.02 ± 0.08	-0.02 ± 0.12	0.02 ± 0.11	0.01 ± 0.12	0.04 ± 0.11
	Plyometric	-0.05 ± 0.11	-0.09 ± 0.12	-0.07 ± 0.11	-0.05 ± 0.10	-0.07 ± 0.16	-0.06 ± 0.17
	Isometric	-0.03 ± 0.13	0.00 ± 0.09	-0.03 ± 0.12	-0.05 ± 0.13	-0.05 ± 0.12	-0.04 ± 0.16
0-10m Sprint (s)	Squat	-0.02 ± 0.06	-0.02 ± 0.05	-0.03 ± 0.09	-0.01 ± 0.08	-0.02 ± 0.07	0.02 ± 0.08
	Plyometric	-0.03 ± 0.07	-0.04 ± 0.07	-0.04 ± 0.06	-0.02 ± 0.07	-0.06 ± 0.08	-0.01 ± 0.09
	Isometric	0.03 ± 0.12	0.01 ± 0.07	-0.02 ± 0.13	-0.02 ± 0.09	-0.02 ± 0.09	0.00 ± 0.11
10-20m Sprint (s)	Squat	0.00 ± 0.12	0.00 ± 0.06	0.00 ± 0.06	0.03 ± 0.08	0.02 ± 0.07	0.02 ± .08
	Plyometric	-0.03 ± 0.11	-0.04 ± 0.05	-0.03 ± 0.07	-0.02 ± 0.06	-0.01 ± 0.08	-0.04 ± 0.09
	Isometric	0.00 ± 0.12	-0.03 ± 0.05	0.01 ± 0.06	0.00 ± 0.06	0.01 ± 0.07	-0.01 ± 0.07
CMJ (cm)	Squat	-0.03 ± 6.70	1.90 ± 6.69	3.25 ± 10.17	0.47 ± 7.93	0.99 ± 8.52	1.79 ± 10.06
	Plyometric	0.44 ± 4.42	1.28 ± 7.07	1.14 ± 7.82	1.48 ± 6.73	0.54 ± 6.49	1.59 ± 6.70
	Isometric	-0.43 ± 4.95	1.71 ± 6.06	0.06 ± 7.13	-0.57 ± 6.27	0.28 ± 5.99	1.52 ± 7.67

Finally, to explore factors that might impact the individual response and magnitude of the PAP response, we looked at the relationship between the change in 20m sprint times relative to strength and lean mass. To do this, the average change (post-pre) in 20m sprint times across all interventions (excluding control) and all time points (excluding 20s post) was calculated for a given subject. Correlations were then determined for this value relative to a subject's 1RM strength expressed relative to body weight (1RM/BW) and their percent fat free mass (%FFM). The same correlations were determined for the average change in sprint times across the control session. These data are displayed in Figure 6.

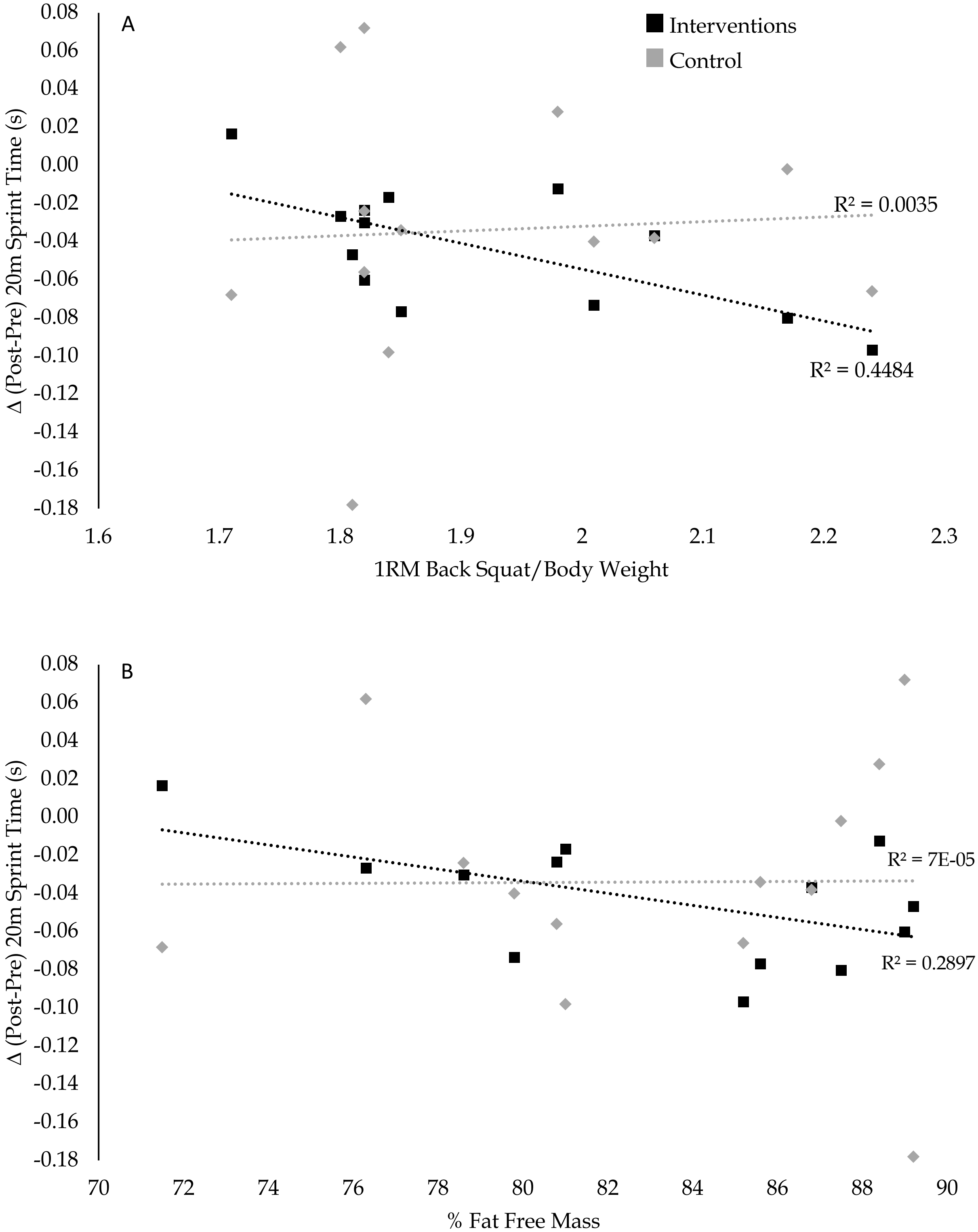


Figure 6. Relationship between change (post-pre) in 20m sprint times averaged across post testing time points (4, 8, 12, 16, 20 min) for all interventions (squat, plyometric, isometric) and control relative to back squat strength to weight ratio (A) and percent fat free mass (B).

DISCUSSION

The purpose of the present study was to determine the effect of different PAP stimuli on jump height and 20m sprint times in resistance trained, college-aged men and women. Additionally, we sought to determine if the time course for optimal performance following the PAP stimulus differs across stimuli. This was examined by having participants perform a CMJ and 20m sprint prior to and following one of four interventions (dynamic resistance, weighted plyometric, isometric, control).

For the 0-20m sprints (Figure 2), times were faster following all PAP interventions at various time points relative to the control session. This is supported by Turner, et al (20) who revealed improved performance between weighted plyometric, non-weighted plyometric, and control interventions. McBride, et al (12) also found between-condition differences with heavy squats compared to control. Our findings contrast the findings of Lim et al. (11) who did not see a benefit in 30m sprint times following dynamic resistance or isometric interventions compared to a control intervention. This may be due to fewer time points of collection, as they only assessed sprint times at baseline and 4-minutes post intervention. In the present study, sprint times improved at the 4 and 8-minute mark for the traditional dynamic resistance trial, but were not improved until 12 to 20 minutes post intervention for the isometric trial.

The between-conditions differences at different time points in this study help to establish when to perform each PAP method prior to competition. For example, the squat intervention resulted in faster sprint times than control at the 4 and 8-minute time points. Additionally, subjects ran faster following the plyometric intervention than the control at the 8-minute time point. However, the isometric intervention did not result in faster sprint times relative to the control until the 12 and 16-minute time point. This would suggest that when isometric exercise is employed as a PAP stimulus, it should be performed further from the start of competition than when utilizing dynamic resistance and plyometrics.

When simply focusing on time, sprint times were faster at later time points post-intervention when compared to baseline and 20-seconds post intervention. This is consistent with results by Turner, et al. (20), who showed faster sprint velocities 4-minutes post plyometric exercise, and at 8-minutes post weighted plyometric exercise. This is important because if the PAP stimulus occurs too close to the subsequent performance, fatigue may impair outcomes. In the present study, the isometric intervention resulted in the greatest decrement in sprint performance at the 20-second post time point. It also took longer for the isometric intervention to result in a PAP effect than the other methods. This is somewhat consistent with Kovačević, et al. (10) where standing broad jump distance decreased 30 seconds following a 6-second maximum voluntary isometric semi-squat exercise. However, performance tended to be improved at 60- and 90-seconds post-intervention.

When examining mean values for the 0-10m split times, it appears that the plyometric intervention was consistently faster post-intervention when compared to the other interventions. This may indicate that the plyometric intervention creates a greater PAP response in the initial acceleration of sprint performances. However, in the 10-20m sprint times, mean values for the squat and isometric interventions were consistently faster post-intervention when compared to the plyometric. As previously proposed, phosphorylation of myosin regulatory light chains (8, 18) and an increase in motor unit recruitment (22) are the driving mechanisms of PAP (19). Given that ground reaction forces and ground contact times differ during the acceleration phase of sprinting vs. maximal velocity running, future research could help to determine if the observed differences in split times across modes is related to any mechanistic difference.

The lack of a main effect for condition for CMJ in the present study may be driven by relying on a single jump to assesses performance at any given time point. Burkett, et al. (2) showed improvements in CMJ following a plyometric PAP intervention, but they measured 3 CMJ and reported the peak performance at each time point, whereas the present study utilized a single jump. Lastly, the smaller effect of PAP on CMJ compared to sprinting observed in the present study is consistent with a meta-analysis by Seitz et al. (16). Given that sprinting over a given distance requires repeated efforts of explosive force production, as opposed to a single CMJ, it may be easier to observe PAP when sprinting is the outcome of interest.

There are limitations to the present study. While we accept the limitation that the testing of CMJ/sprinting at previous time points could potentiate subsequent time points, the control group provides a useful reference at any given time point for this limitation. Additionally, as previously mentioned, the reliance on a single CMJ at baseline and any given time point may increase the individual variability observed. All subjects completed the testing trials within a 2-week time span. While at least 48 hours of recovery were given between trials, there is a potential that outside training over the duration of the entire study could impact the results. The randomization of the sessions should however address some of this concern. Lastly, while it is possible that the CMJ jump performed immediately prior to the 20m sprint at teach time point could have impacted the sprint results, a single CMJ is not particularly taxing and this type of preparatory movement prior to getting into the starting blocks is not uncommon in competitive sprinting.

In conclusion, our data indicate that 20m sprint times can be improved relative to control given any one of the three post-activation potentiation stimuli: squat, plyometric, or isometric. Additionally, we have suggested the ideal time to complete each intervention prior to competition as indicated by the present data: squat (4-8 minutes), plyometric (8 minutes), isometric (12-16 minutes). Future research can help to determine whether or not the repeated testing bouts performed prior to these particular time points is necessary in order to see a benefit from the PAP stimulus, or if the PAP stimulus alone is sufficient. Future research can also help to determine what other internal and external factors influence the responsiveness of athletes to potentiating stimuli. However, given that the plyometric and isometric interventions resulted in similar sprint performance improvements as the back squat in this study, these PAP stimuli can be seen as an attractive alternative to traditional resistance exercise in a pre-competition, field setting where access to space and equipment may be limited.

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