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Comparison of Post-Activation Potentiation Methods on Power and Sprint Acceleration

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ABSTRACT

Post-activation potentiation (PAP) is a stimulus used to enhance performance by performing specific interventions prior to subsequent explosive movements. The purpose of this study was to determine the effect of different PAP methods on power and sprint acceleration in resistance trained, college-aged men and women. A total of 13 subjects participated in the study. 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 given, followed by a baseline countermovement jump (CMJ) and 20-meter sprint. Following the warmup and baseline measurements, the subjects then performed one of the four interventions. After the intervention, CMJ and 20-meter sprint measurements were completed again at 20-seconds, 4, 8, 12, 16, and 20-minutes. The results from this study showed significantly faster 0-20m sprint times, $p < .05$, at 4, 8, 12, 16, and 20-minutes post-intervention compared to baseline and 20-seconds post-intervention. Also, significantly faster 0-20m sprint times, $p < .05$, were shown for the squat intervention compared to the 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 any of the PAP stimuli can be effective at improving sprint performance, there may be a specific optimal time window for each.

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INTRODUCTION

Before the start of a competitive event, a warmup is conducted by athletes. Pre-competition warmups are designed to prepare athletes for optimal performance in a subsequent anaerobic activity (4). Generally this is done to warm the body's skeletal muscles, and includes static or dynamic stretching, dynamic or explosive drills, and between two and four max effort sprints. A general pre-competition warm up can take anywhere between twenty minutes and thirty minutes to complete. Some research has shown that warmup times of fifteen minutes at an intensity of 60-70% can improve subsequent anaerobic performances (16). Increases in muscle temperature, nerve conductivity, metabolic reaction speeds, blood flow, and oxygen consumption are some of the benefits that follow an active warmup. Furthermore, an induction of post-activation potentiation (PAP) is another desirable benefit to the warmup (20).

PAP is a stimulus used in the athletic performance populations to promote force and peak power output (PPO) for performance enhancements and advantages. Increases in muscle contraction speeds and force production have been shown to be benefits of PAP (10). The PAP stimulus is achieved by previous muscle contractions of a muscle group, and can have a positive or negative effect (11). This is done by performing traditional dynamic resistance training, maximum voluntary isometric contractions, or plyometric exercises as a PAP stimulus prior to a subsequent explosive movement.

Positive effects are the result of the muscle group being potentiated, leading to an increase in force and power production, while potential negative effects could result from the muscle group being fatigued leading to a decrease or no change in force and power production. Two physiological mechanisms have been proposed as the reason for PAP. One is the phosphorylation of myosin regulatory light chains, and the other is an increase in motor unit recruitment (17). With the phosphorylation of myosin regulatory light chains, it is believed that actin and myosin are more sensitive to calcium released from the sarcoplasmic reticulum. This theory points to an increase in the rate of cross-bridging between actin and myosin resulting in increased muscle contraction speeds and greater force production (10). With the increase of motor unit recruitment, it is believed 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 the stimulation (17).

Contrary to this, fatigue is a potential disadvantage of PAP and therefore research has been done to find the optimal time the PAP stimulus should be performed prior to explosive, anaerobic activities. While there is some consensus that the PAP stimulus should be performed ~4-12 minutes prior to the subsequent anaerobic activity, there is a lack of research comparing each protocol and PAP stimulus method to determine what is optimal in a pre-competition field setting. This is important because some PAP stimuli may be more feasible to performing in a field setting than others, such as plyometrics compared to traditional resistance training.

In previous research related to PAP as a potential performance enhancer in athletic populations, there have been many methods utilized as a PAP stimulus, including traditional dynamic resistance training, plyometric exercise, and maximum voluntary isometric contractions. Traditional dynamic resistance training would consist of working against a load of a given percent of 1 repetition max (1RM) for single or multiple working sets on exercises such as back squatting. Plyometric exercises would consist of repeated attempts to produce power while working against the body's mass, or loaded with an external resistance such as a weighted vest, while utilizing the stretch-shortening cycle (11). Maximum voluntary isometric contractions would typically consist of statically contracting a muscle group without changing the length of the muscle, either loaded or unloaded for a time of no greater than 10-seconds.

Traditional dynamic resistance training is generally done with compound lifts such as back squat, bench press, deadlift, etc. The optimal load, reps, and sets that should be performed has been previously investigated. In a meta-analysis of PAP and power conducted by Wilson, et al. (19), results showed that moderate intensities, 60-84%, and multiple sets optimized potentiation better than heavy intensities, >85%, and single sets. Contrary to this, Gilbert & Lees (8), conducted a study with the purpose to establish the physical and temporal characteristics of PAP of muscle function in elite male athletes following maximum strength and power exercise. Subjects performed 5 repetitions of back squat with 1RM load, >85%. Following the repetitions, subjects then performed an isometric maximum voluntary contraction at 2-, 10-, 15-, 20-, and 30-minutes. Results showed a 10% increase in rate of force development (RFD) at 15-minutes, and a 13% increase in RFD at 20-minutes. This shows that greater loads are also capable of eliciting an increase in PAP stimulus. Fitness level, experience, and strength of athlete could be potential effects on loading percentage and recovery time after PAP protocol to observe improvements.

In a study conducted by Kilduff, et al. (11) examining the recovery time required to observe enhanced muscle performance following a bout of heavy resistance training, the traditional dynamic resistance training protocol was implemented. The methodology of this implemented protocol was back squatting ≥80% of 1RM for 3 sets of 3 repetitions. The subjects, 20 professional rugby players, performed a countermovement jump (CMJ) for baseline data collection prior to performing 3 sets of 3 repetitions on back squat. Immediately after back squatting, within 15-seconds, and every 4-minutes after up to 24-minutes, the subjects performed another CMJ. PPO, peak rate of force development, and CMJ height were observed at each 4-minute mark. The results showed a significant increase, $p \leq 0.05$, in PPO, peak rate of force development, and CMJ height occurring at the 8-minute mark after the resistance training compared to the baseline test. Mean PPO observed at baseline was reported at 5347W, while at the 8-minute mark mean PPO observed was reported at roughly 5500W. Mean peak rate of force development at baseline was 12358N, compared to 16290N observed at the 8-minute mark.

Crewther et al. (5) conducted a study examining the acute potentiating effects of back squat on athlete performance with a focus on movement specificity and the individual timing of potentiation. Nine male rugby players performed 3 protocols on separate occasions. Before each protocol performance testing was conducted, then again at roughly 15-seconds, 4-, 8-, 12-, and 16-minutes after the 3 repetition max (RM) of back squat. The three testing measurements were countermovement jump (CMJ) height, 5- and 10-meter sprint performances, and 3-meter horizontal sleds push with 100kg loading. Results showed a significant improvement in CMJ height at 4- and 12-minutes compared to baseline.

Traditional resistance training for PAP has been shown to be a successful stimulus when performed ~4-12 minutes prior to a subsequent performance at PPO. However, unless the coach, athletic trainer, etc. decides to take the equipment required, squat rack, barbell, weighted plates, etc. to a pre-competition setting, using this protocol would not be the most feasible in a field setting.

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 muscle motor units by utilizing the stretch-shortening cycle (1). This leads to an increase in power and rate of force development (14). Research has been conducted using plyometric exercises as a PAP stimulus.

Turner, et al. (18) used a plyometric protocol by examining the influence of alternating-leg bounding on sprint acceleration. Twenty-three plyometric trained men performed seven 20-meter sprints, with 10-meter splits, at baseline, roughly 15-seconds, 2-, 4-, 6-, 8-, 12-, 16-minutes after a walking control or 3 sets of 10 repetitions of alternate-leg bounding using body mass, plyometric group, or body mass plus 10%, weighted plyometric group. These results conclude that weighted and un-weighted plyometric exercises are capable of enhancing athletic performance. However, weighted plyometric exercises have been shown to result in greater effects on enhancing athletic performance.

In addition, Burkett, et al. (3) examined the effectiveness of specific and non-specific warmups on vertical jump test performed by athletic men. Twenty-nine men in speed positions in football performed four different warmup protocols. The protocols consisted of submaximal jump warmup, weighted jump warmup, stretching warmup, and no warmup. The submaximal jump warmup consisted of subjects performing 5 CMJ at 75% intensity of their past maximum vertical jump score. The weighted jump warmup consisted of subjects performing 5 CMJ onto a 63.5 cm-high box holding dumbbells equaling 10% of their body weight. The stretching warmup consisted of subjects performing 14 different stretches held of 20-seconds each. Two minutes following the warmup protocol, 3 vertical jumps were conducted with the best jump recorded used for analysis. Results showed an increase in mean vertical jump height in stretching, submaximal jump, and weighted jump warmup compared to no warmup with a significant difference only in the weighted jump warmup. Also, there was a significant difference between weighted jump warmup compared to submaximal jump warmup and stretching warmup.

In addition, McBride, et al (13) examined whether performing high force or explosive force movements prior to sprinting would improve running speed. Fifteen football players performed heavy-loaded squats (HS), loaded CMJ (LCMJ), or a control (C) warm up over the course of 3-weeks. The HS protocol was 1 set of 3 repetitions at 90% of subjects 1RM. The LCMJ protocol was 1 set of 3 repetitions at 30% of subjects 1RM. The C protocol was a 5-minute warmup on a stationary bike at standardized resistance at a cadence of 70 rotations per minute (RPM). Following each warmup protocol a timed 40-meter dash was conducted with 10-, 30-, and 40-meter splits at 4-minutes. No significant differences were shown in the 10-meter or 30-meter sprint times across all protocols. This could be due to the amount of sets and reps in the plyometric group. In comparison with studies like Turner, et al (2015) the reps and sets were 3 sets of 10 repetitions versus 1 set of 3 repetitions as conducted in the current study. This method may not have been sufficient enough to elicit a PAP response in the subjects.

Similar to heavy dynamic resistance exercise, it appears that weighted plyometric exercises seem to elicit a beneficial PAP response overall. However, with studies like McBride, et al (13) there are some inconsistencies with the use of plyometric interventions as a PAP intervention. Also, unlike traditional resistance training, weighted plyometric exercise does not require as much equipment, other than a weighted vest, and could be useful in the field or pre-competition setting. However, further research is needed to compare if one PAP stimulus is more favorable and if the time course of the benefits differ.

Maximum voluntary isometric contractions have also been studied as a potential PAP stimulus. Previous research has shown contractions held between 3- and 10-seconds for single and multiple sets to be methods used when implementing isometric protocol for PAP. Rixon, et al. (15) conducted a study aiming to examine influence of type of muscle contraction, isometric vs dynamic, on PAP as demonstrated by changes in jump height and power output. The study consisted of 30 subjects, 15 men and 15 women, who performed 3 sets of CMJ with the first set being baseline measurements. The second and third sets were performed after either an isometric protocol or a dynamic protocol. The isometric protocol consisted of 3 sets of 3-second isometric holds on back squat with 2-minute rest intervals. Following the protocol, at a 3-minute time point, the subjects then performed a CMJ. The results showed that jump height was significantly higher after the isometric protocol compared to both the pretest and dynamic protocol values. Also, jump power was significantly greater for the isometric protocol compared with jump power from pretest and after dynamic protocol.

In addition, Kovačević, et al. (12) researched acute effects of maximal isometric contractions on explosive power of lower limbs. The study consisted of 9 elite senior tennis players performing a maximal isometric concentric semi-squat contraction for 6-seconds. Following the 6-second contraction, subjects then performed a standing long jump or a vertical jump at 30-, 60-, and 90-seconds. The results showed a significant difference in the vertical jump test at 60- and 90-seconds after the 6-second isometric contraction compared to the vertical jump conducted before the isometric contraction.

There was no significant difference in the standing long jump test at any time after the isometric contraction compared to the measurements taken before the contraction. This could possibly be due to the exercise chosen for the PAP intervention. A vertical jump resembles the semi-squat more than the standing long jump does. Also, the direction of force application during the concentric semi-squat is vertical just as the direction of force application during the vertical jump. As for the standing long jump, the direction of force application is more horizontal than it is vertical.

Also, when examining isometrics Demura, et al. (6) conducted a study observing maximal force production from a wide or narrow stance during an isometric squat at various knee flexion degree angles. The wide stance protocol was at 140% width of the shoulders, while the narrow stance protocol was at a 5-cm width. Results showed significantly greater force production with a wider stance compared to a narrow stance at each knee flexion degree. The various knee flexion degree angles were 90˚, 60˚, 30˚, and parallel. The results showed that there was no significant difference between parallel and 90˚. However, the force production was significantly greater with decreasing knee flexions degree angles. Parallel and 90˚ force production was less than 60˚, which was less than 30˚. This shows that wider stance widths and shallower squat depths are ideal as an isometric PAP stimulus.

Overall these studies show that isometric PAP protocols are also effective in enhancing power abilities. While isometric devices could be developed to be used in the field that might be less bulky than traditional, resistance training equipment, it is still unclear if one particular PAP stimulus is more favorable.

As discussed in some of the specific PAP stimulus studies, the timing after the PAP stimulus is important in its impact on PPO. In some research the speed and/or power test is performed again immediately after the protocol is implemented roughly 15-seconds after. Then, 3-, 4-, or 5-minute recovery periods are given before the test is performed again and data is collected. Most research does not seem to test beyond 24-minutes post-protocol. This is likely due to the decline in measurements as total recovery time becomes extended. Another method used with these protocols is the same format as the previously explain, but rather than testing in either 3-, 4-, or 5-minute recovery periods, a predetermined set time post-protocol is chosen and the test is conducted again at that time only. Each protocol has been shown to enhance speed and power performance testing, but the question still remains as to which protocol and method would be best for pre-competition and if the time course for the benefits varies based on method.

Lastly, the research also shows that the percentage of enhancements in the performances, post-intervention, varies. This could be due to the muscular strength levels of the subjects. Stronger and more conditioned subjects tend to show greater enhancements compared to weaker and less conditioned subjects. Gourgoulis, et al. (9) in a study examining the effect of a warm up program including submaximal half-squats on vertical jumping ability showed that subjects who were able to squat more than 160kg had a 4.01% increase in their CMJ height, whereas those who were not able to squat more than 160kg had a 0.42% increase in there CMJ height.

In summary, PAP is a method that can be used during a pre-competition setting prior to subsequent anaerobic activity such as speed and power testing. This method has the potential to enhance performance of subsequent anaerobic activity. Protocols such as traditional resistance training, plyometric exercises, and maximum voluntary isometric contractions are used to elicit PAP response. Research has shown enhancements in speed and power measurements following the use of these protocols, but the percentage of these enhancements and time course vary. Further research is needed to compare the protocols used for PAP to determine which protocol would be best for a pre-competition, field setting. Therefore, the purpose of this study is to determine the effect of different PAP methods (dynamic resistance, weighted plyometric, isometric) on power and sprint acceleration in resistance trained, college-aged men and women. A secondary purpose is to determine if the time course for optimal performance following the PAP stimulus differs across different PAP methods.

METHODS

Experimental Approach to the Problem

Testing for an individual subject was conducted on 5 separate days. A minimum of 48-hours was given in between testing days to allow subjects to receive a complete recovery. On the first day subjects reported to the testing site for measurements in height, weight, body fat percentage (DEXA), back squat 1 repetition max testing, and familiarization of the PAP protocols. On the other 4 testing days, subjects performed in a randomized order 1 of 3 different PAP methods (dynamic resistance, plyometric, isometric) or a control session. On each testing day, a standardized warm-up was completed followed by baseline testing of a CMJ and 20-meter sprint. After the baseline testing, the subjects completed 1 of the 3 PAP methods or the control method. Then, roughly 20-seconds after the post-activation potentiation method or controlled method, and 4-, 8-, 12-, 16-, and 20-minutes, the subjects repeated the same testing as they did at baseline. All procedures were approved by the Institutional Review Board prior to the start of the study and subjects provided informed consent before beginning testing.

Subjects

A total of 13 resistance trained, college-aged men and women completed the study. Subjects were selected based upon their strength and training status. Subjects were required to have a training status of working out at least 3 times or more per week for the past 4 months and a squat 1 repetition max of at least 1.7 times their body weight.

Procedures

Post-Activation Potentiation Methods

Three PAP methods (dynamic resistance, plyometric, isometric) were used for this study in addition to a control trial. Sessions were performed in a randomized, crossover design with at least 48 hours between sessions.

The dynamic resistance training stimulus required the subjects to back squat 87% of their 1RM for 3 sets of 5 repetitions with a 3-minute break between sets. This method was chosen as it is similar to a previous successful study done by Kilduff, et al. (11).

The plyometric training stimulus required the subjects to perform 3 sets of 5 vertical jumps with a weight vest adding 10% of the subject's body mass to the movement. A 3-minute break between sets was given to ensure the subjects had adequate recovery. Weighted plyometric was chosen over unweighted plyometric as previous studies have shown that weighted plyometrics elicit a better PAP response (2).

The maximum voluntary isometric contraction PAP stimulus consisted of a back squat simulated movement for 3 sets of 3-seconds of a maximal voluntary isometric contraction. Subjects were positioned into a squat position of roughly 30˚ to perform this isometric back squat. The chosen position was based on Demura, et al. (6) who showed that 30˚ angle squats produced more force compared to other angles. Also, the chosen amount of sets and seconds were chosen based on studies conducted by French, et al. (7), and Rixion, et al. (15).

For the controlled session, subjects did not perform any PAP method. Instead, subjects performed a 4-minute walk after the standardized warmup and then performed the testing again.

Outcome Measures

Countermovement jump height was measured using the Just Jump mat (Probotics Inc., Huntsville, AL). When instructed, subjects stepped onto the mat and performed a

CMJ. The 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 their body. Then, after exploding up into the jump and bringing their arms up also, the subjects were instructed to land onto the mat with their legs straight. All subjects underwent familiarization testing at the initial study visit to learn the proper technique. CMJ height was measured at baseline and at 20 seconds and 4-, 8-, 12-, 16-, and 20-minutes following each intervention.

Sprint times were measured using automatic timing gates (Brower Timing TC-System, Draper, UT) placed at 0-, 10-, and 20-meters. Following the CMJ subjects performed a 20-meter sprint to measure acceleration speed. Subjects were instructed to start half of a meter behind the timing gates placed at the 0-meter mark. Subjects were in a split stance starting position prior to starting the sprint. Then, the subjects sprinted through the 20-meters and the timing gates. Times from distances of 0 to 10-meters, 10-meters to 20-meters, and 0 to 20-meters were used for data collection. Sprint times were measured immediately following the CMJ measurements 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. Using the change values from baseline for each dependent variable, the main effects for condition and time (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.

RESULTS

A total of 13 subjects participated in the study. Subject demographics can be seen in Table 1. All subjects were resistance and anaerobically trained with the female subjects being able to squat between 1.7 and 2x their body weight, and the male subjects being able to squat between 1.8 and 2.24x their body weight.

For CMJ height, mean values from baseline to 20-minutes post are displayed for each condition in Figure 1A. There was a main effect for time ($p = .018$), 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. Also, there was a main effect for time ($p = .007$) shown in the change in CMJ height as shown in Figure 1B. Pairwise comparisons for time revealed significantly greater changes in CMJ heights at 4 and 8-minutes compared to 20s.

Mean values from baseline to 20-minutes for 0-10m split times are shown in Figure 2A. 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 a significantly 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. A main effect for time ($p = .004$) was shown in the change in 0-10m split times from baseline to post-intervention time points in Figure 2B. Pairwise comparisons for time showed significantly greater decreases in sprint times at 8, 12, 16, and 20 minutes compared to 20 seconds.

For 10-20m split times, mean values from baseline to 20-minutes post are shown in Figure 3A. There was a main effect for time ($p = .003$) and condition ($p = .014$), but no interaction. 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. Pairwise comparisons for condition showed squat and isometric were significantly faster than plyometric and control. There was a main effect for time ($p = .021$) in the change in 10-20m split times shown in Figure 3B. Pairwise comparisons showed a significantly slower 10-20m split time at 20-seconds post compared to the other time points.

Mean values from baseline to 20-minutes for 0-20m sprint times are shown in Figure 4A. 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 interactions, repeated one-way ANOVA were run to compare conditions at a given time point. Pairwise 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. When analyzing the change in 0-20m sprint times, a main effect for time ($p \leq .001$) and a trend towards interaction ($p = .053$) was shown in Figure 4B. Pairwise comparisons for time showed significantly greater changes 0-20m sprint times at 4, 8, 12, 16, and 20-minute time points post-intervention compared to 20-seconds. Also, there was a significantly greater change in 0-20m sprint times at 16-minutes post-intervention compared to 4-minutes.

DISCUSSION

This study looked to determine the effect of different PAP methods (dynamic resistance, weighted plyometric, isometric) on power and sprint acceleration in resistance trained, college-aged men and women and to also determine if the time course for optimal performance following the PAP stimulus differs across different PAP methods. This was examined by having participants perform a CMJ and 20-meter sprint prior to and following one of four interventions (dynamic resistance, weighted plyometric, isometric, walking control).

For 0-20m sprint times (Figure 4A), the PAP interventions all elicited significantly faster sprint times compared to control at various time points. This is supported by Turner, et al (18) who revealed significant differences between weighted plyometric, non-weighted plyometric, and control interventions. McBride, et al (13) also found between-condition significant differences showing that heavy squats resulted in faster sprint times compared to control.

The significant differences between-conditions at different time points in this study help to establish when to perform each PAP method prior to competition. For example, the squat intervention was significantly different compared to control at the 4 and 8-minute time points. Also, the squat intervention had the fastest mean sprint time at the same time point at 3.19 seconds. This may give implication that utilizing the squat intervention 4 to 8-minutes prior to sprint performance could possibly result in greater PAP. The plyometric intervention was significantly better than control as well at the 8 minute time point. However, the isometric intervention was significantly different compared to the control at the 12 and 16-minute time points, and significantly different compared to the squat intervention at the 20-minute time point. Also, the isometric intervention had the fastest mean sprint time at 3.17 seconds at the 12 and 16-minute time points, and 3.16 seconds at the 20-minute time point. This may give implication that utilizing the isometric intervention 12 to 20-minutes prior to sprinting could possibly result in greater PAP.

Later time points post-intervention resulted in faster sprint times when compared to baseline and 20-seconds post intervention. This is consistent with results by Turner, et al (18), who showed significant differences in average 10-meter sprint velocities at 4-minutes compared to baseline in the plyometric group, and at 8-minutes compared to baseline in the weighed plyometric group. This is important because if the PAP stimulus occurs too close to the subsequent performance, fatigue may impair the outcomes.

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 give implication that the plyometric intervention gives 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. Future research could help to determine the potential mechanism for these differences. As previously proposed, phosphorylation of myosin regulatory light chains and an increase in motor unit recruitment are the driving mechanisms of PAP (17). Perhaps the plyometric intervention stimulates more neural drive and increased motor unit recruitment, whereas the squat and isometric interventions stimulates greater cross bridging and force production through the phosphorylation of myosin regulatory light chains.

When examining mean value sprint times across time, the plyometric intervention appeared to be the only intervention not affected by initial fatigue as reported by Turner, et al (18) who found significant differences at the 4 and 8-minute time points compared to immediately after the intervention, ~15-seconds. This difference may be due to the difference in volume and recovery of the plyometric interventions. This study utilized a method of adding 10% of body weight for 3 sets of 5 jumps, 15 total reps, separated by 3-minutes of recovery. Whereas Turner, et al (18) utilized a method of adding 10% of body weight for 3 sets of 10 alternating leg-bounds, 30 total reps, separated by a walk-back recovery with both 10 alternating leg-bound plus recovery lasting ~25-seconds.

In the present study, the isometric intervention resulted in the greatest decrement in sprint performance at the 20-second post time point and it took longer for the isometric intervention to result in a PAP effect than the other methods. This seems to be consistent with Kovacevic, et al (12) who also found decreases in standing broad jump from initial jump at 30-seconds following a 6-second maximum voluntary isometric semi-squat exercise. However, greater but not significant broad jumps occurred at 60-seconds and 90-seconds following the semi-squat exercise when compared to the initial jump. Also, in the same study, significant increases in vertical jump heights occurred at 60-seconds and 90-seconds following the semi-squat exercise when compared to the initial jump.

The results from this study also expressed a PAP effect in later time points for CMJ height when compared to baseline and 20-seconds post-intervention. This result is supported by Kilduff, et al. (11) who showed that CMJ height was significantly different at 8-minutes post-intervention compared to baseline. Also, Crewther, et al (5) showed significant differences in CMJ height at 4, 8, and 12-minutes post-intervention compared to baseline and 15-seconds post-intervention. While there were no significant condition effects for CMJ, a greater change in CMJ height occurred with the squat intervention. This is supported by Rixon, et al (15) who found a significantly higher jump height between-conditions following the PAP intervention. However, Rixon (15) found that the isometric intervention performed better than the dynamic squat intervention. This result may be driven by the difference in sets and repetitions between the two interventions. The isometric intervention was 3 sets of 3-second maximum voluntary contractions, whereas the dynamic squat intervention was 1 set of the subject's 3 repetition max. Lastly, the lack of a main effect for condition for CMJ in the present study may be driven by single effort output of the activity, whereas the 20-meter sprint is multiple efforts of output. Furthermore, Burkett, et al. (3) showed improvements in CMJ following a plyometric PAP intervention, but they measured 3 CMJ and took the best at each time point, whereas the present study just used a single jump.

PRACTICAL APPLICATIONS

Our data indicate that 20m sprint times can be improved relative to control given any one of the three post-activation potentiation interventions: squat, plyometric, or isometric. Furthermore, these results indicate the ideal time to complete each intervention prior to competition: squat (4-8 minutes), plyometric (8 minutes), isometric (12-16 minutes). The fact that isometric and plyometric interventions can improve performance similar to a traditional back squat is important because these interventions can be easily applied at a pre-competition setting because of their mobility and ease of use. The squat intervention however, although it resulted in a PAP effect, is not so mobile and easily applied at a pre-competition setting due to the equipment required. This study, and its findings, gives coaches and athletes information on ways that are easily applicable to express PAP during pre-competition settings to enhance performance.

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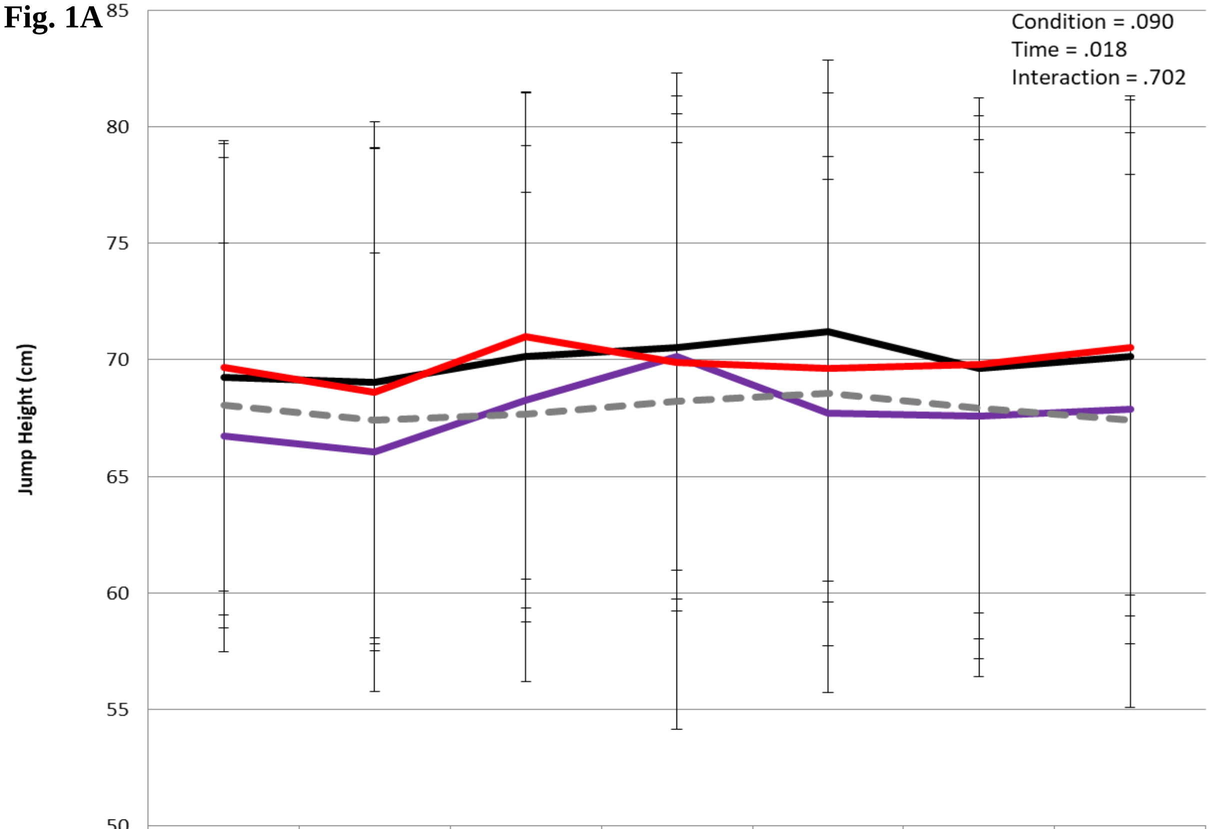
Table 1. Demographics values of resistance trained men and women

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

All values represent mean ± SD.

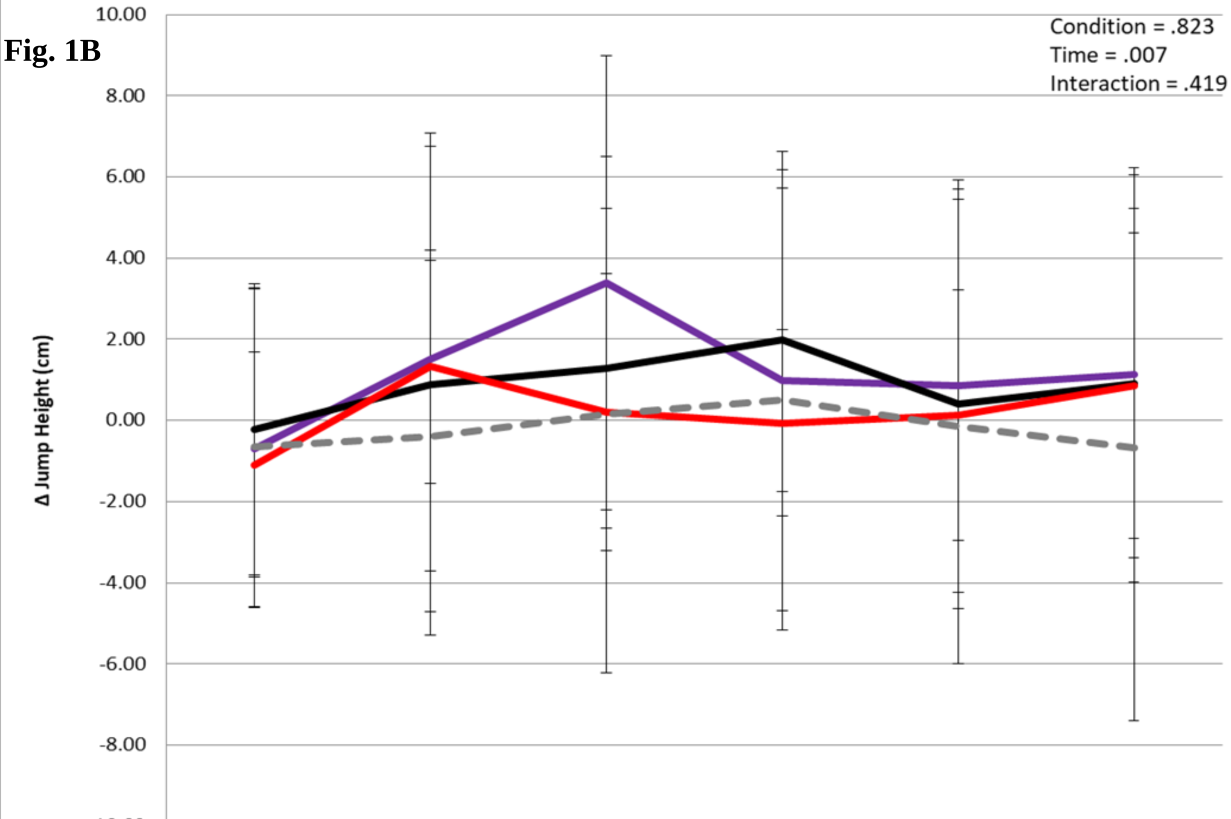
Fig. 1A



	Baseline	20s	4min	8min	12min	16min	20min
Squat	66.74	66.06	68.26	70.14	67.72	67.59	67.87
Plyo	69.24	69.02	70.13	70.53	71.23	69.64	70.16
Iso	69.67	68.59	71.00	69.88	69.61	69.81	70.53
Cont	68.07	67.41	67.69	68.22	68.58	67.93	67.41

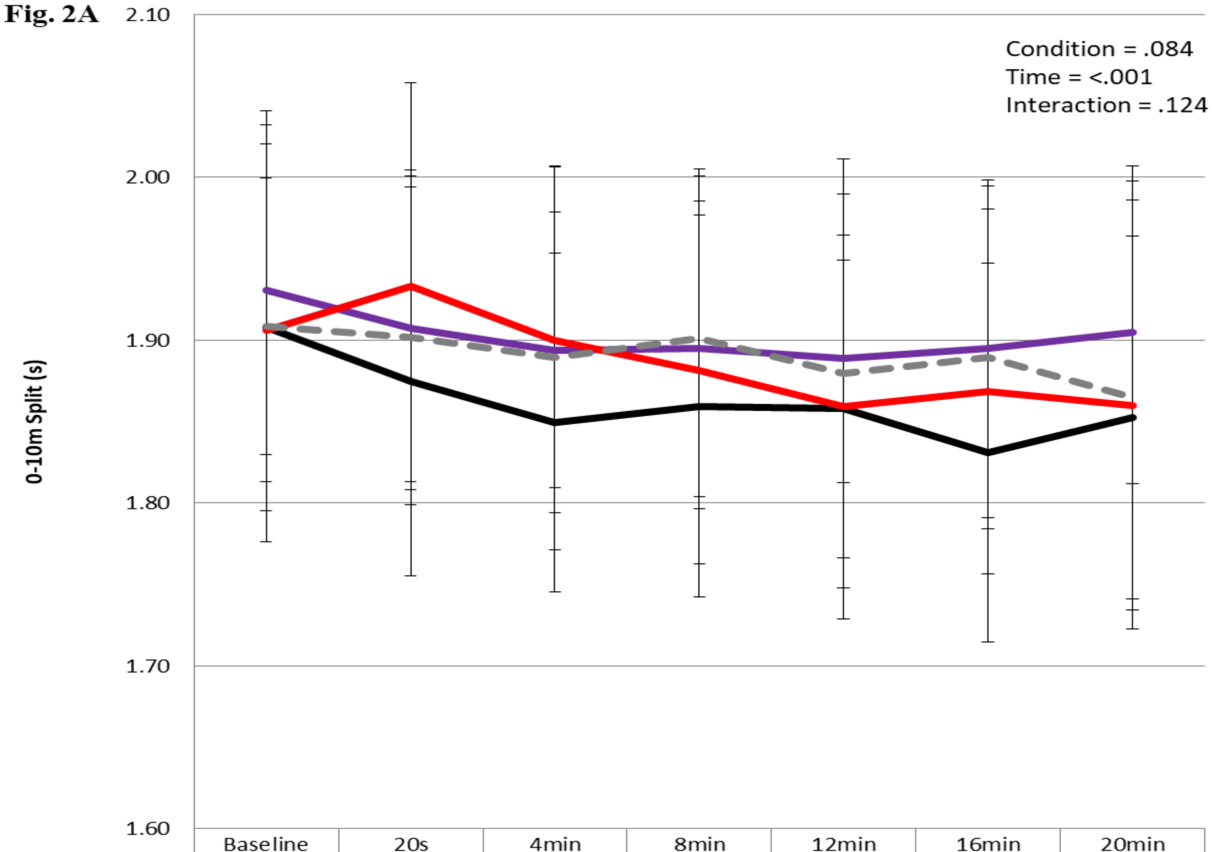
Time Point

Fig. 1B



	20s	4min	8min	12min	16min	20min
Squat	-0.68	1.52	3.39	0.97	0.85	1.13
Plyo	-0.22	0.89	1.29	1.99	0.40	0.92
Iso	-1.09	1.33	0.21	-0.06	0.13	0.86
Cont	-0.66	-0.38	0.15	0.51	-0.14	-0.67

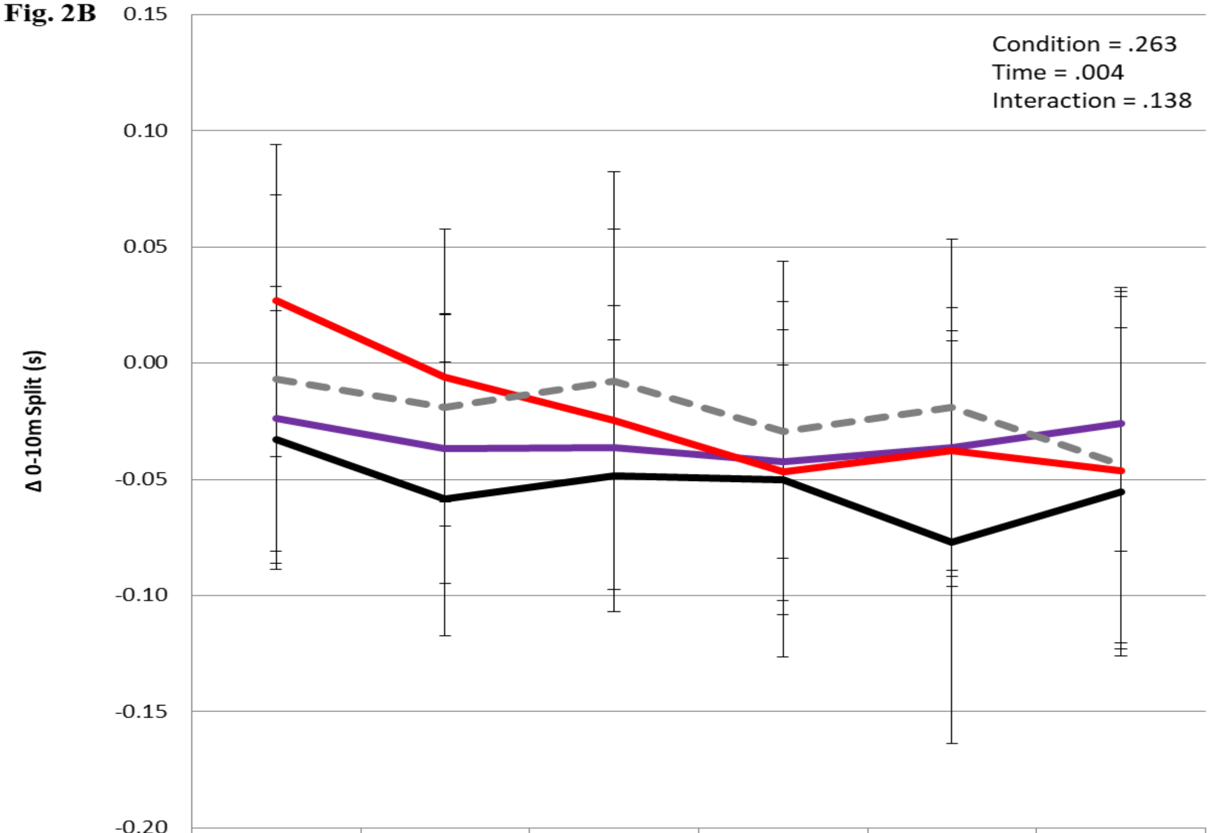
Fig. 2A



	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

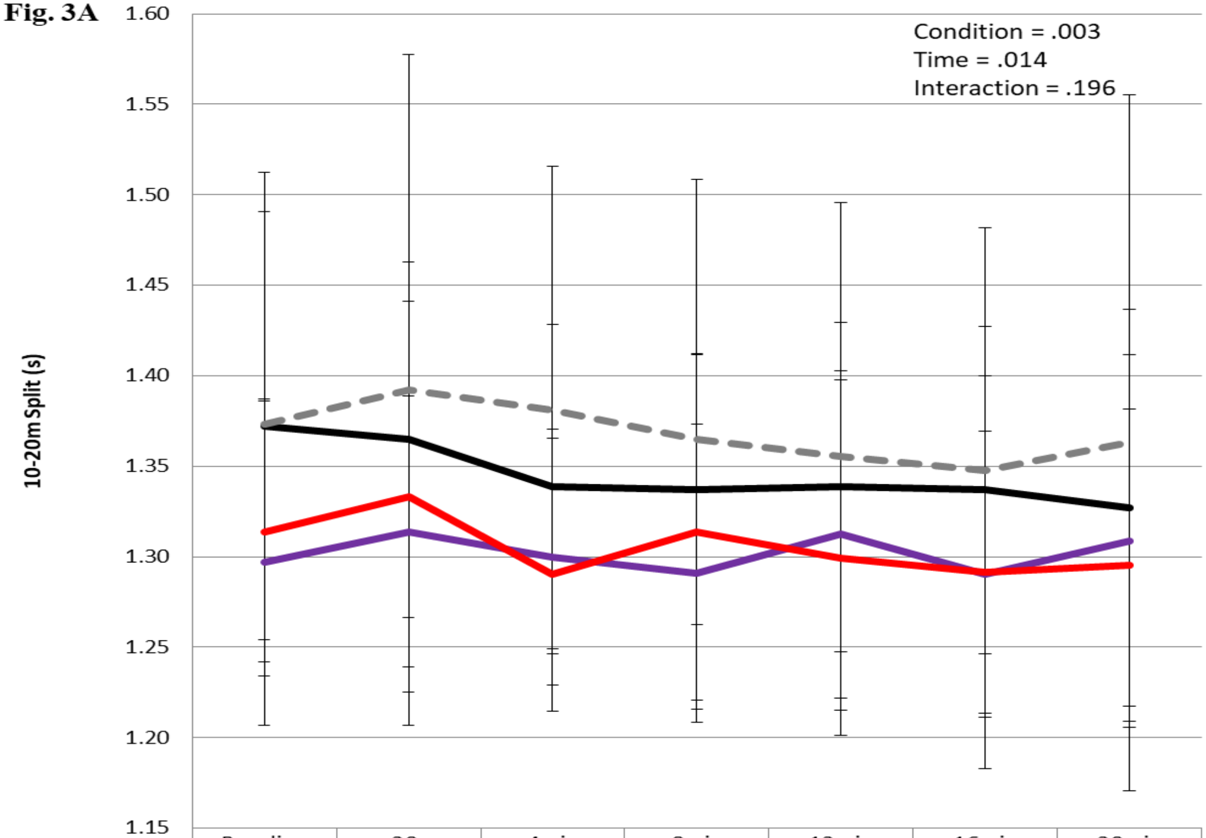
Fig. 2B



	20s	4min	8min	12min	16min	20min
Squat	-0.02	-0.04	-0.04	-0.04	-0.04	-0.03
Plyo	-0.03	-0.06	-0.05	-0.05	-0.08	-0.06
Iso	0.03	-0.01	-0.02	-0.05	-0.04	-0.05
Control	-0.01	-0.02	-0.01	-0.03	-0.02	-0.04

Time Point

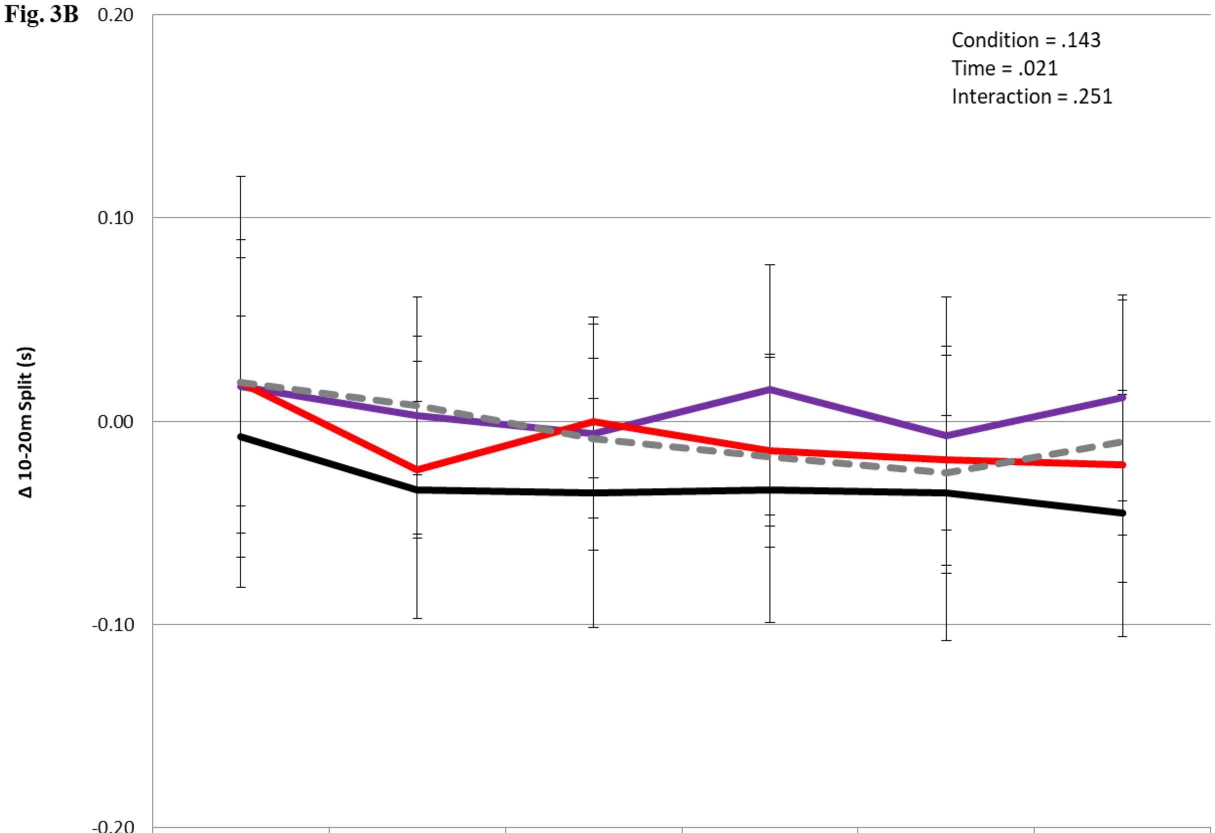
Fig. 3A



	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

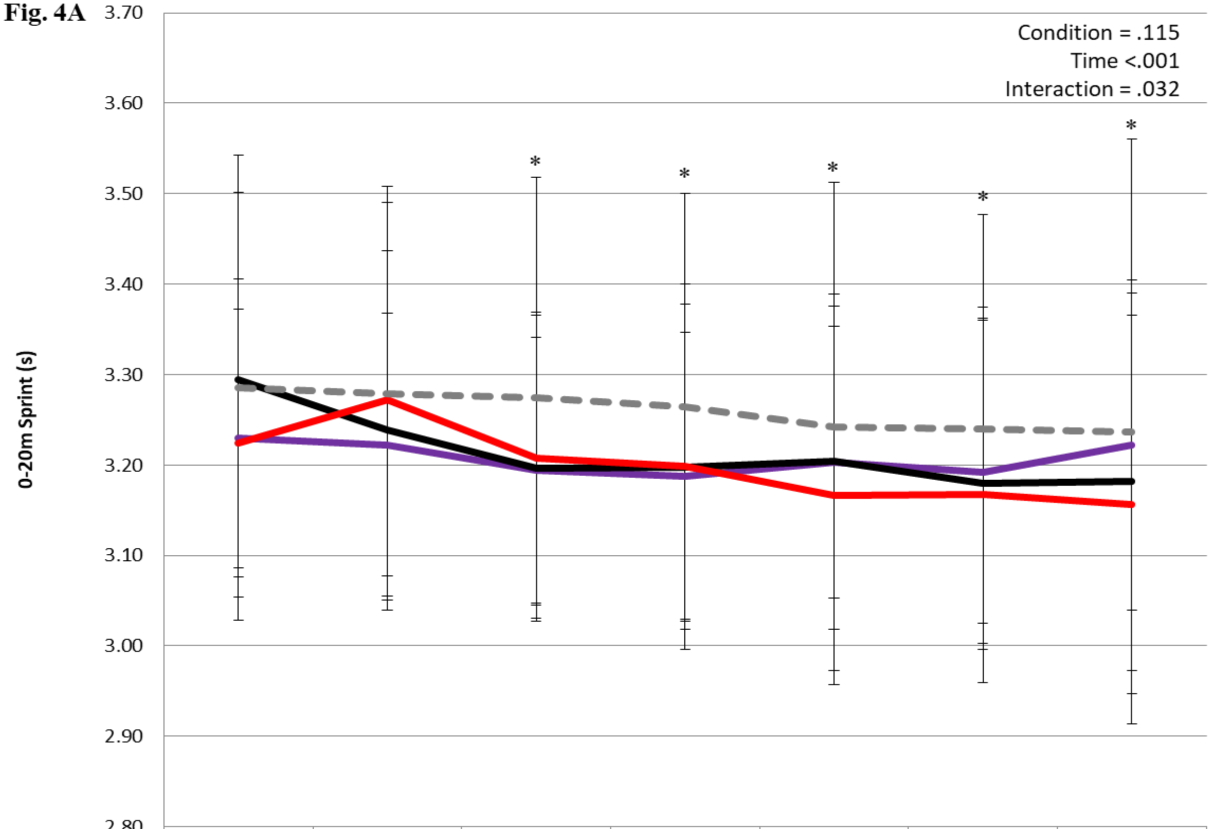
Fig. 3B



	20s	4min	8min	12min	16min	20min
Squat	0.02	0.00	-0.01	0.02	-0.01	0.01
Plyo	-0.01	-0.03	-0.04	-0.03	-0.04	-0.05
Iso	0.02	-0.02	0.00	-0.01	-0.02	-0.02
Control	0.02	0.01	-0.01	-0.02	-0.03	-0.01

Time Point

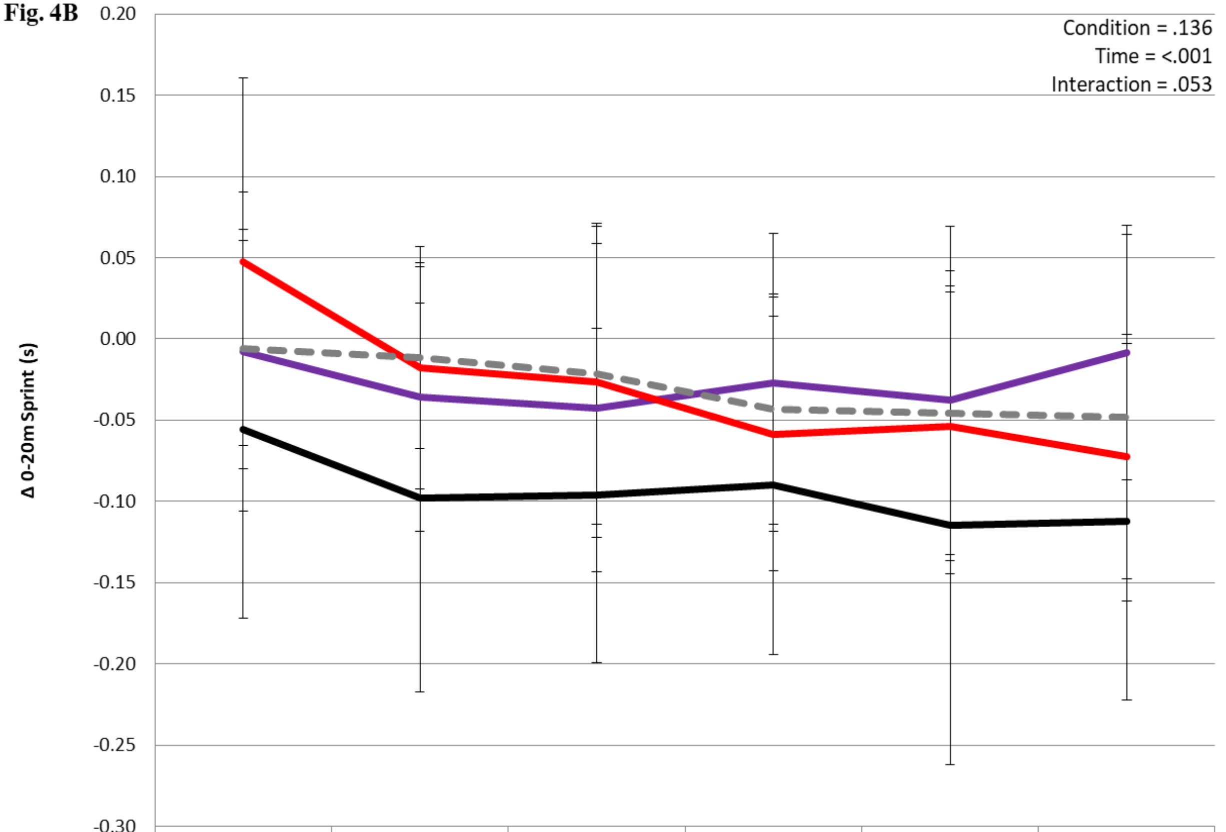
Fig. 4A



	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 ‡
Control	3.29	3.28	3.27	3.26	3.24	3.24	3.24

Time Point

Fig. 4B



	20s	4min	8min	12min	16min	20min
Squat	-0.01	-0.04	-0.04	-0.03	-0.04	-0.01
Plyo	-0.06	-0.10	-0.10	-0.09	-0.11	-0.11
Iso	0.05	-0.02	-0.03	-0.06	-0.05	-0.07
Control	-0.01	-0.01	-0.02	-0.04	-0.05	-0.05

Timpoint

Figure 1. A) CMJ height (cm) at baseline, 20 seconds, 4, 6, 8, 12, 16, and 20 minutes post intervention for squat, plyometric, isometric, and control sessions. B) Change in CMJ height (cm) from baseline to 20 seconds, 4, 8, 12, 16, and 20 minutes post intervention for squat, plyometric, isometric, and control sessions.

Figure 2. A) 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. B) Change in 0-10m split time (s) from baseline to 20 seconds, 4, 8, 12, 16, and 20 minutes post intervention for squat, plyometric, isometric, and control sessions.

Figure 3. A) 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. B) Change in 10-20m split time (s) from baseline to 20 seconds, 4, 8, 12, 16, and 20 minutes post intervention for squat, plyometric, isometric, and control sessions.

Figure 4. A) 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. B) Change in 0-20m split time (s) from baseline to 20 seconds, 4, 8, 12, 16, and 20 minutes post intervention for squat, plyometric, isometric, and control sessions.

VITA

Aaron Piper, a graduate of Duncanville High School, enrolled at Stephen F. Austin State University located in Nacogdoches, Texas during the fall semester of 2013. He received a Bachelor of Science in Kinesiology from Stephen F. Austin State University after the spring semester of 2017. Upon graduating, during the summer of 2017, he began working at the Michael Johnson Performance located in McKinney, Texas. After that summer, he returned to Stephen F. Austin State University to enroll in the Kinesiology Graduate Program, and to work as a volunteer Track & Field coach for the University.

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