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A Comparison of Warm-Up Modalities on Upper Body Force Production Measures

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A COMPARISON OF WARM-UP MODALITIES ON UPPER BODY FORCE PRODUCTION MEASURES

by
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ABSTRACT

MARY LANGFORD: A Comparison of Warm-Up Modalities on Upper Body Force Production Measures
(Under the Direction of Dr. John Garner)

Warm-ups are often initiated before an athletic event in order to prepare the athlete's body for competition by increasing blood flow to the working muscles. When a warm-up also activates nerve-muscle function, producing a level of high-intensity power even after the muscle contraction occurs, it is known as post-activation potentiation (PAP). Most PAP warm-ups include high-load, low-velocity conditioning contractions whereas a low-load, high-velocity conditioning contraction may be a more user-friendly warm-up. Therefore, the purpose of this study was to investigate the effects of PAP after low-load, high-velocity conditioning contractions on subsequent upper body power exercises. Ten recreationally trained males (age: 23.2 yrs; height: 178.1 cm; mass: 88.3 kg; see Table 1) volunteered to participate in three testing sessions, each separated by 24-48 hours. The testing conditions were 10% of 1RM bench press and 20% 1RM bench press. After the conditioning contraction, participant's performed a plyometric push-up immediately after and then 4- and 8-minutes after the warm-up. The plyometric push-up was performed on a force platform in order to gather the dependent variables: ground reaction force, normalized ground reaction force, and rate of force development. No main effect or interaction was found for any variables ($p>.05$). Subjects showed no strength improvements after performing the conditioning contractions, and further

research must be done in order to validate other research on low-load, high-velocity conditioning contractions.

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INTRODUCTION

Warm-ups are often initiated before the onset of a strength and conditioning training session or an athletic sporting event. The premise of a warm-up is to prepare the body for a training session by increasing blood flow and oxygen to the working muscle while also removing carbon dioxide and other wastes from the muscles (Andrade et al., 2015; Cilli, Gelen, Yildiz, Saglam, & Camur, 2014; Ribeiro & Romanzini, 2014). Warm-ups can be seen as a rehearsal for the body before it performs in an athletic event (Ribeiro & Romanzini, 2014). During this time, the body can physically prepare itself for the demands of a training session desired by a sports coach or exercise professional. Traditionally, warm-ups have included a moderate intensity run followed by static stretching. However there have been recent studies suggesting a warm-up also known as a general warm-up, can have no effect or adverse effects on the athletic performance of an athlete (Cilli et al., 2014). Therefore, strength and conditioning coaches have looked for a better way to ensure their athletes are prepared for the workout (Andrade et al., 2015). Another method proposed by strength and conditioning coaches involves a warm-up that is specific towards the needs of that athlete along with performing movements similar to the actions within a training session or athletic event. This style of warm-up is known as a specific warm-up, which could better prepare the athlete for future training sessions along with improving athletic performance (Cilli et al., 2014).

Specific warm-ups prepare the body for a training session or athletic event because this style of warm-up is similar to the activities that will be performed in the actual event (Andrade et al., 2015). A specific warm-up might include high knee pulls, skipping, or various jumping exercises to prepare the individual for a task (Cilli et al., 2014). Unlike general warm-ups, specific warm-ups can have other beneficial effects, too. Specific warm-ups may also activate nerve-muscle function, which can produce a level of high-intensity power even after the muscle contraction occurs. This phenomenon is known as post-activation potentiation (PAP) (Cilli et al., 2014).

Exercise scientists began to see the effects of PAP as early as the 1970s (Gouvêa, Fernandes, César, Silva, & Gomes, 2013). They noticed that when a high-intensity specific warm-up, known as a conditioning contraction, preceded a similar exercise, the exercise performance was greater when comparing to a group who had not performed the warm-up (Gouvêa et al., 2013). Since then, coaches have been using the effects of PAP to increase their athletes' performance (Gouvêa et al., 2013). However, there is a recovery period that seems to be optimal for PAP to occur before fatigue sets in (Gouvêa et al., 2013). This recovery period occurs between the conditioning contraction and the exercise itself, and many studies show that this optimal rest period is between 7 to 12 minutes after the conditioning contraction (de Assis Ferreira, Panissa, Miarka, & Franchini, 2012; Gouvêa et al., 2013; Turner, Bellhouse, Kilduff, & Russell, 2015).

PAP can influence force, rate of force development (RFD), and power (Bullock & Comfort, 2011; de Assis Ferreira et al., 2012; Tillin & Bishop, 2009). All of these variables can improve the performance outcome of an athlete. Most research on PAP focuses on high load/low velocity (HLLV) conditioning contractions (Bullock &

Comfort, 2011; Turner et al., 2015). HLLV exercises include maximal effort, or close to maximal effort, warm-ups to elicit a PAP effect (Bullock & Comfort, 2011; de Assis Ferreira et al., 2012; Tillin & Bishop, 2009). On the other hand, low load/high velocity (LLHV) conditioning contractions include more sets and repetitions of a submaximal load (Bullock & Comfort, 2011). LLHV exercises may be more practical than HLLV exercises because LLHV exercises require less equipment and are therefore more user-friendly before a competition (Turner et al., 2015).

Furthermore, a number of studies have shown increases in ground reaction force (GRF), normalized ground reaction force (nGRFz), and RFD after a HLLV exercise; however, there is limited research involving LLHV exercises (Bullock & Comfort, 2011; Turner et al., 2015). LLHV exercises may be a more effective warm-up than the HLLV exercises (Turner et al., 2015). If both types of conditioning contractions contain the same total volume, they should elicit the same PAP effect. However, there is a lack of research regarding the effects of PAP while matching total volume in LLHV exercises. The purpose of this study was to investigate the effects of PAP between two different loads (10% and 20% of a given 1RM bench press) on subsequent upper body power exercises (plyometric push-ups). This study also aimed to determine how long after the conditioning contraction PAP is elicited, specifically looking at immediately post-stimulus, and 4- and 8- minutes post-stimulus.

Hypotheses

Ground Reaction Force

H_{01}: There will be no statistically significant differences in ground reaction force values between conditions.

H_{A1}: There will be a statistically significant difference in ground reaction forces values between conditions.

Considering the total volume of LLHV conditions is equal to the volume of the previous HLLV conditions and these PAP studies have shown increases in GRF, it is expected that there would be a statistically significant increase in ground reaction force in this study. For this reason, this study expects to reject the null hypothesis for ground reaction force.

Normalized Ground Reaction Force

H_{02}: There will be no statistically significant differences in normalized ground reaction force values when ground reaction force is divided by participant body weight.

H_{A2}: Differences between conditions in calculated normalized ground reaction force will be statistically significant.

As above, this study expects to reject the null hypothesis for normalized ground reaction force contingent upon the null hypothesis rejection for ground reaction force. Normalized ground reaction force is derived from the same force platform data with its calculation as ground reaction force divided by the participant's body weight.

Rate of Force Development

H_{03}: There will be no significant differences between conditions when rate of force development is calculated from force plate data.

H_{A3}: Differences between rate of force development calculations between conditions will be statistically significant.

> Previous studies testing PAP elicitation after a conditioning contraction reported statistically significant improvements in rate of force development (Anthi, Dimitrios, & Christos, 2014; Hodgson, Docherty, & Robbins, 2005; Tillin & Bishop, 2009). This information would suggest that the current study would also show improvements in RFD. Based on this data, this study expects to reject the null hypothesis.

Limitations and Delimitations

While we tried to recruit a wide range of individuals, most of them were students in the Health, Exercise Science, and Recreation Management department. This limits the population sample because it could be suggested that most of these individuals are similar in terms of training status and knowledge of strength and conditioning. This sample is not representative of the entire student population.

A delimitation of this study was the exclusion of females. While most of the research on PAP thus far focuses on males, we are not able to make broad claims about the effects of PAP when only a part of the total population is represented. Another delimitation of this study was the exclusion of untrained individuals. Again, while most of the PAP research is limited to recreationally trained individuals, we can only assume our results will translate to other recreationally trained individuals. Therefore, our results exclude untrained individuals. Outside of subject criteria, another delimitation was the exclusion of lower body power. While a pilot study cannot include every variable, it must be noted the results collected only translate for upper body power.

Definitions

Post Activation Potentiation (PAP): an acute and temporary enhancement of muscle performance as a result of its contractile history (Turner et al., 2015)

Hoffman Reflex (H-Reflex): sensory fibers are activated in nerves of muscles unrelated to original action area and reflex electrical stimulation occurs (Ebben, 2006)

Rate of Force Development (RFD): calculated as the slope of the ground reaction force curve relative to the onset of concentric force production over time intervals of 0-100, 0-200, and 0-250 milliseconds (Rodgers & Cavanagh, 1984)

Normalized Ground Reaction Force: ground reaction force value measured from the force plate divided by participants' body weight, expressed in Newtons/kilogram (Rodgers & Cavanagh, 1984)

Ground Reaction Force: the forces that act on the body as a result of interaction with the ground; equal and opposite to those that the body is applying to the ground (Rodgers & Cavanagh, 1984)

One Repetition Maximum (1RM): the greatest amount of weight that can be lifted with proper technique for only one repetition (Baechle & Earle, 2008)

Power: equal to the work done divided by the time during which the work is being done (Rodgers & Cavanagh, 1984)

Warm-up: muscle actions performed before a higher muscle demand, usually before high-intensity competitive or recreational events take place (Andrade et al., 2015).

REVIEW OF LITERATURE

Warm-ups

Strength and conditioning is a field within exercise science devoted to increasing individual performance during athletic competition. The overall goal is to enhance an individual's power output. While conditioning is defined as general health and fitness, strength is defined as the ability to overcome resistance and produce maximal force (Baechle & Earle, 2008; Chandler & Brown, 2008). Resistance exercises may include the use of free weights, weight machines, or the individual's body weight. Power is the product of force and velocity; to increase power, individuals must increase force and/or velocity (Chandler & Brown, 2008). The force-velocity relationship is displayed as the force-velocity curve; this curve demonstrates an inverse relationship, meaning that during concentric muscle contractions, as force increases, velocity decreases, and the opposite is also true (Chandler & Brown, 2008). Therefore, the goal of a strength and conditioning coach would be to move the athletes force-velocity curve up and to the right in order to produce greater power (Baechle & Earle, 2008).

While the force-velocity curve demonstrates the principle behind increasing power, the specific adaptation to imposed demands (SAID) principle gives the methods to increase power (Chandler & Brown, 2008). The SAID principle is a general explanation for how muscular and neural performance are increased in individuals over a given period of time (Baechle & Earle, 2008; Chandler & Brown, 2008). More explicitly, it means the demand placed on the body dictates the adaptation that will occur, known as specificity. The law of specificity states that "the more similar the training activity is to the actual sport movement, the greater the likelihood that there will be an active transfer of performance to that sport" (Chandler & Brown, 2008). For instance, if a strength and conditioning coach's goal for an athlete is to improve his power during high-speed movements, exercise selection should mimic the same recruitment patterns (Chandler & Brown, 2008). The SAID principle also includes other techniques for increasing performance, such as the principle of progressive overload (Chandler & Brown, 2008). The principle of progressive overload is based on having a load placed on the body that is greater than what is normal to achieve an adaptation (Baechle & Earle, 2008; Chandler & Brown, 2008). An individual cannot perform the same exercise at the same volume or intensity continuously over time and still expect to see increases in power because the body adapts to the load placed upon it (Chandler & Brown, 2008). Increasing the load of an exercise, adding repetitions to the current load, altering repetition velocity, changing rest period length, and/or increasing volume are all ways to elicit an adaptation on the body (Chandler & Brown, 2008). All of these factors must be adjusted based on the individual's strength and conditioning performance. Research has shown in order to optimize performance, individuals should perform warm-ups to provide acute physiological change to the body, including increased blood and oxygen flow to muscles and enhanced speed of nerve impulses and waste removal (Ribeiro & Romanzini, 2014). Before performing any resistance training, the individual should prepare the body for a workout by performing a warm-up protocol.

The purpose of a warm-up is to prepare the individual for a preceding activity, reduce the risk of injury, and potentially improve exercise performance (Andrade et al., 2015; Faigenbaum, 2012; Ribeiro & Romanzini, 2014). Under the umbrella of warm-ups are general (GWU) and specific warm-ups (SWU) (Andrade et al., 2015; Faigenbaum, 2012; Ribeiro & Romanzini, 2014). GWUs involve low-intensity exercises, and SWUs involve specific-skill exercises. GWUs aim is to increase heart rate, blood flow to muscles, body and muscle temperature, respiration rate, and decrease the viscosity of joint fluids (Faigenbaum, 2012). SWUs are unique to the athletes sport or proceeding training exercise (Andrade et al., 2015). These movements can include arm circles, hurdle-unders mobility, and light body weight squats that can be used before a sport specific activity (Faigenbaum, 2012). Warm-ups should last between 8 and 12 minutes and gradually increase in intensity throughout (Faigenbaum, 2012).

To compare the effects of general and specific warm-ups on explosive muscular performance, Andrade et al. (2015) used running as a GWU and countermovement (CMJ) and depth jumps (DJ) as a SWU in their research. It was found that both general and specific warm-ups induced a significant increase in explosive concentric-only muscle actions for the squat jump (SJ) and CMJ. However, SWUs alone caused a significant increase ($p=0.006$) in the stretch-shortening cycle (SSC) muscle performance for the DJ from a 60-cm high platform (Andrade et al., 2015). The increase in the SSC muscle performance was inferred because of the increase in vertical jump performance. This suggests only high-intensity muscle activity warm-ups like SWUs induce rebound activities (Andrade et al., 2015). The results demonstrated there was a significant increase in JH in both the exercises post- warm-up (Cilli et al., 2014). These findings are similar to previous studies where CMJ and SJ were tested after a specific warm-up, which is significant because it may show that SWUs can cause increases in performance (Andrade et al., 2015; Cilli et al., 2014).

Ribeiro and Romanzini (2014) investigated the effects of warm-ups on submaximal resistance training. This study is different from other investigations mentioned earlier because it focuses on muscular failure over multiple sets during submaximal exercises versus maximal force, performance, and power (Andrade et al., 2015; Cilli et al., 2014). Participants in this study performed a warm-up condition and no warm-up (control) condition preceding three upper and lower body exercises: bench press, squat, and arm curl exercises. Each of these exercises consisted of 4 sets at 80% 1RM to concentric failure (Ribeiro & Romanzini, 2014). They found there was no significant difference between warm-up and control conditions (Ribeiro & Romanzini, 2014). However, the participants were untrained and 4 sets at 80% 1RM may have been too heavy of a load considering their training status (Ribeiro & Romanzini, 2014). Warm-ups have shown to increase muscular performance during exercises, and there are many different theories as to how they work (Andrade et al., 2015; Cilli et al., 2014; Ribeiro & Romanzini, 2014). One of these theories behind how warm-ups help performance is known as potentiation (Ebben, 2006; Froyd, Beltrami, Jensen, & Noakes, 2013; Hodgson et al., 2005).

Potentiation

Potentiation is a phenomenon in which torque production, in response to a single electrical stimulus, increases after a brief isometric maximal voluntary contraction (MVC) (Froyd et al., 2013). Potentiation effects are specific to each muscle group and are based on the ideal length of an MVC for each group (Anthi et al., 2014; Ebben, 2006;

Froyd et al., 2013). Miyamoto et al. (2012) found that a single MVC of 5 seconds was sufficient to potentiate the quadriceps and did not produce fatigue. If torque production can be manipulated, potentiation has the ability to increase performance during high-intensity exercises (Ebben, 2006; Hodgson et al., 2005; Tillin & Bishop, 2009). This is vital as athletes and coaches are constantly trying to find non-chemical ergogenic ways to improve performance.

Potentiation is described based on the mechanism of action or by the time interval in which it is induced after the MVC (Ebben, 2006; Froyd et al., 2013; Garceau, Petushek, Fauth, & Ebben, 2010). Two important types of potentiation are concurrent activation potentiation (CAP) and post-activation potentiation (PAP). CAP is a phenomenon where there is a performance enhancement when muscles are active remotely, and concurrent with, the activation of a prime mover (Ebben, 2006). The remote muscles are active and maximally contracted, are known as remote voluntary contractions (RVCs). As an RVC occurs, the prime mover can produce more power (Ebben, 2006). This occurs through a process known as functional synergy, where activation of one area of the motor cortex activates another area simultaneously (Ebben, 2006). Through these mechanisms, CAP is potentially activated. CAP is maximized through mastication or jaw-clenching and through other RVCs (Ebben, 2006). CAP is a simultaneous event, and therefore, its effects are seen almost instantly (Ebben, 2006; Garceau et al., 2010). Garceau et al. (2010) investigated the time course of CAP during an isometric knee extension and found that CAP effects are accrued during the first 1000 ms after the RVC.(Garceau et al., 2010)

Research on CAP focuses on its impact during a variety of performance activities including the CMJ, back squats, the JS, and race start times (Andrade et al., 2015; Cilli et al., 2014; Garceau et al., 2010; Ribeiro & Romanzini, 2014). Ebben et al. (2008) found that CAP is manifested through jaw clenching during the CMJ. Participants performed CMJs on a force platform while clenching their teeth with a mouth guard. Teeth clenching on the mouth guard served as the RVC. Rate of force development (RFD) and time to peak force (TTPF) both showed significant increases from the control condition (no jaw clenching) to the testing condition (with jaw clenching). RFD was 19.5% greater in jaw clenching conditions and TTPF was 20.15% less in jaw clenching conditions versus the control conditions (Ebben, Flanagan, & Jensen, 2008). This suggests that CAP can be induced and enhance CMJ performance.

Other studies have also shown that CAP may enhance power performance. Ebben et al. (2010) investigated how RVCs increase force-based performance on back squats and JS. The intervention condition included RVCs consisting of clenching the teeth with a mouth guard, forcefully gripping a barbell, and performing the Valsalva maneuver. This testing condition was compared with a control condition with no RVCs. They found that peak ground reaction force (PGRF) and RFD during the first 100 ms (RFD-100) were higher in the RVC condition when compared to the control condition for back squat and JS. PGRF increased by 4% in the back squat and 2.9% in the JS. RFD-100 increased by 23.1% in the back squat and 32.2% in the JS. JH was also increased by 26.1% in the RVC condition when compared with the non-RVC condition in the JS (Ebben, Kaufmann, Fauth, & Petushek, 2010). The results suggest that RVCs may significantly enhance back and jump squat performance.

CAP may also potentially be induced and provide an increase in power performance during the start of races. Issurin and Verbitsky (2013) found that using a CAP technique provided a start reaction time advantage of .05 s and also a start efficiency of .08 s on a 15 m swimming race. In swimming races, every millisecond is important, especially at the Olympics level (Issurin & Verbitsky, 2013). The RVC condition included teeth clenching and voluntary contraction of the abdominal muscles; these conditions were induced at the beginning of the starting command, but participants were able to unclench their teeth after takeoff. The start reaction time advantage and start efficiency are believed to have occurred through an increase in RFD caused by the RVC, which led to a CAP effect (Issurin & Verbitsky, 2013). By decreasing start reaction time and increasing start efficiency, athletes would be able to complete the race more quickly than normal. This kind of ergogenic aid would be very useful in competitive swimming.

CAP is an important phenomenon in the study of warm-ups because CAP may augment non-chemical ergogenic benefits that can be useful in performance activities (Froyd et al., 2013; Hodgson et al., 2005; Tillin & Bishop, 2009). Another type of potentiation that also may enhance subsequent performance is called post-activation potentiation (PAP) (Anthi et al., 2014; Hodgson et al., 2005; Tillin & Bishop, 2009). PAP is induced by a voluntary conditioning contraction performed at or near maximal intensity in order to induce a potentiation effect after a recovery period (Anthi et al., 2014; Hodgson et al., 2005). PAP is different than CAP because it occurs after a recovery period and therefore must overcome fatigue (Anthi et al., 2014; Hodgson et al., 2005; Tillin & Bishop, 2009). Also, while CAP is activated through remote voluntary contractions, PAP activation occurs through the same group of muscles in the conditioning contraction (Anthi et al., 2014; Hodgson et al., 2005; Tillin & Bishop, 2009). Like with CAP, there is more than one mechanism for activating PAP (Anthi et al., 2014; Hodgson et al., 2005; Tillin & Bishop, 2009).

There are two proposed mechanisms as to how PAP occurs: 1) at the muscular level and 2) at the neural level (Anthi et al., 2014; Hodgson et al., 2005; Tillin & Bishop, 2009). The first mechanism is related to the phosphorylation of the myosin regulatory light chains during muscle contraction. Myosin contains six subunits, two heavy chains, and four light chains. Each pair of light chains contains an essential light chain and a regulatory light chain (RLC) (Anthi et al., 2014; Tillin & Bishop, 2009). In order for a muscular contraction to occur, calcium (Ca^{2+}) must leave the sarcoplasmic reticulum, thus activating the light chain kinase (Anthi et al., 2014). The light chain kinase phosphorylates the RLCs at the hinge of the head and tail. This addition of P_i changes the myosin head causing it to move further away from the thick filament backbone (Anthi et al., 2014). The movement of the myosin head away from the backbone increases the number of cross-bridge binding sites, which in turn creates a potential for greater muscular contraction. The greater potential for a muscular contraction leads to the greater ability to produce force, RFD, or power, which may be signified through the PAP effect (Anthi et al., 2014; Hodgson et al., 2005; Tillin & Bishop, 2009).

The second mechanism for PAP activation is found at the neural level. This mechanism proposes that the increase in RFD after conditioning contractions is due to an increase in motor neuron excitability and the recruitment of more motor units, which can be explained by the Hoffman (H) reflex (Anthi et al., 2014; Hodgson et al., 2005; Tillin & Bishop, 2009). The nervous system alters muscle contraction intensity by changing the number of active motor units or by changing the firing rate of active units (Anthi et al., 2014). Henneman's size principle states that motor units are recruited in order from smaller units to larger units and thus are recruited from slower to faster fibers (Anthi et al., 2014). From this definition, it is implied that in order to activate fast motor units, the muscle contraction must be of high overall intensity. Conditioning contractions should, therefore, increase motor unit recruitment to increase force production and RFD (Anthi et al., 2014; Tillin & Bishop, 2009). They increase the recruitment by activating the H-reflex. This reflex predominantly assesses problems in the neural pathway, but it can also be used in PAP to recruit more motor units because there is a link between H-reflex amplitude and the number and size of recruited motor units (Hodgson et al., 2005). A change in the amplitude of an H-wave reflects a synaptic change at the spinal cord which can indicate three possibilities: 1) change in the excitability of motor neurons 2) change of neurotransmitter released or 3) change in the intrinsic properties of the motor neurons (Hodgson et al., 2005). Thus, when there is an increase in the H-wave amplitude, there is an implied increase in stimulus from the Ia afferent neurons to the muscle (Hodgson et al., 2005). This increased stimulus to the muscle leads to a rise in recruitment of motor units (Anthi et al., 2014). With the recruitment of more motor units, muscles may be able to produce more force, RFD, or power for preceding athletic performance (Tillin & Bishop, 2009).

With PAP, overcoming the onset of fatigue after the conditioning contraction and before PAP is elicited has been an area heavily researched in the strength and conditioning literature. Many sources indicate the greatest PAP effect occurs around 7 to 12 minutes post-conditioning contraction in recreationally trained individuals (de Assis

Ferreira et al., 2012; Gouvêa et al., 2013; Turner et al., 2015). A meta-analysis revealed the effects of PAP on jumping performance after various recovery times (Gouvêa et al., 2013). It was found that the interval from 8-12 minutes may be an optimal recovery period between a conditioning contraction and JH for males with at least 6 months of resistance training (Gouvêa et al., 2013). These results have also been demonstrated in explosive bench press tests, where a recovery period of 7 minutes was found to be optimal, and in sprinting exercises, where a recovery period of 8 minutes was optimal (de Assis Ferreira et al., 2012; Turner et al., 2015).

The effects of PAP have been demonstrated in a number of studies including improvements in sprint performance and depth jumps performance (Bullock & Comfort, 2011; Turner et al., 2015). Turner et al. (2015) claimed sprint acceleration performance is enhanced after a plyometric warm-up. This warm-up included three sets of 10 plyometric bounds with either no resistance (plyometric, P condition) or with 10% of body weight added (weight plyometric, WP condition); there was also a control group (C). They found that WP and P sprints were 2.2% faster than C sprints at 4 minutes post-conditioning contraction, and after 8 minutes, WP sprints were 2.9% greater than C and 2.3% greater than P (Turner et al., 2015). This might suggest that PAP was elicited due to the increases in performance, especially after the 8 minute recovery period.

Bullock and Comfort (2011) found PAP might be activated by including 2, 4, or 6 depth jumps (DJs) before a maximal squat exercise (Bullock & Comfort, 2011). The researchers tested five conditions: 2, 4, or 6 depth jumps, a control condition, and a retest condition. Each participant completed the testing condition for that day, then had a 4 minute recovery period before completing a repetition maximum (1RM) back squat. The results revealed that the 2 DJ condition led to a 6.26% increase, the 4 DJ condition resulted in a 6.09% increase, and the 6 DJ condition resulted in a 6.80% increase from the initial 1 RM (Bullock & Comfort, 2011). This study might also suggest PAP was elicited and led to an increase in 1RM strength performance.

Because there is little research on the effects of low load/high repetition conditioning contractions on upper body post-activation potentiation, this study will evaluate whether or not PAP is elicited after a load of 10% and 20% of a given one repetition maximum bench press on a given plyometric push up. This study will also aim to determine how long after the priming activity PAP is elicited. Therefore, the purpose of this study was to investigate the rate of force development, ground reaction force, and normalized ground reaction force elicited from loads of 10% and 20% 1RM on time conditions immediately post-stimulus and 4- and 8- minutes post-stimulus.

METHODS

The aim of this pilot study was to investigate the effects of post-activation potentiation (PAP) at two different loads (10% and 20%) of a given one repetition maximum (1RM) bench press on subsequent plyometric push-up tests. The secondary aim of the study was to determine the optimal recovery period for PAP to be elicited after the bench press exercise. The recovery periods analyzed post-priming activity were immediately post-stimulus, 4- and 8-minutes post stimulus. The testing consisted of three laboratory visits. The first visit was used to collect anthropometrics along with familiarizing participants with the procedures and equipment. Once familiarization of the equipment was covered, baseline data was recorded by testing each participant's 1RM bench press. The remaining three visits served as testing sessions. Each visit was separated by a minimum of 24 hours and no more than 48 hours.

Participants

Ten recreationally trained males (age: 23.2 yrs; height: 178.1 cm; mass: 88.3 kg; see Table 1) who have had at least one year (a minimum of 3 hours per week; 2 days per week) of resistance training, specifically incorporating the bench press exercise, participated in this study. All participants were required to be free of any upper body musculoskeletal or orthopedic injuries within the last year. Participants were informed of the study procedures and signed University approved Institutional Review Board consent documents before the research protocol began.

Table 1: Anthropometric Data

Subject Number	Age (years)	Height (cm)	Mass (kg)
10	23.2 ± 2.20	178.06 ± 5.24	88.27 ± 20.61

Experimental Procedures

At the beginning of the four testing sessions, participants performed a general warm-up (GWU) consisting of 25 jumping jacks, 10 body weight squats, 10 walking knee hugs to full range of motion of plantar-flexion for each leg, 10 forward lunges for each leg, 10 straight leg marches for each leg and 10 push-ups (elbows in).

Visit one served as the familiarization session with explanation of testing protocols, obtaining informed consent, and baseline measurements. On this visit, participants' anthropometric measurements were taken. To standardize the PPU, measurements from the finger tips to the ball of the foot were taken for each participant.

Following these measurements, participants completed the GWU and then began baseline testing. Baseline testing began with three maximal effort plyometric push-ups (PPU), which were completed on the force plate to measure upper body power. The PPUs were completed within the one-minute recovery period. A 10-minute recovery period was given after baseline testing to reestablish baseline conditions. Following the recovery period, participants performed a specific warm-up (SWU) prior to completing the 1RM bench press. The SWU followed the suggested guidelines of the National Strength and Conditioning Association (NSCA). It consisted of 10 repetitions at 40-50% of estimated 1RM. The participants then completed two proceeding SWU sets that progressively increased weight (4-5 repetitions and 2-3 repetitions, respectively) prior to the first 1RM attempt. After the initial three warm-up sets, the participants had 5 attempts to reach their

1RM, with a minimum of two minutes of rest given in between each set. A successful repetition was counted if the participant completed the eccentric and concentric phases by themselves and with proper technique and without guidance from the spotter. Furthermore, the participant had to tap the bar to his chest for the repetition to count. If the chest deformed during the tap, it was considered a “bounce” and the repetition did not count. If the participant did not complete the 1RM within 5 attempts, the participant was asked to reschedule for an additional day prior to completing the intervention sessions to establish a true 1RM. This completed visit one.

Visits two and three served as the PAP intervention sessions. Upon arrival participants performed the GWU as done on day one. Following this, the PAP priming exercise was completed using a free weight straight bar in the Applied Biomechanics Laboratory. The bench press exercise was performed for one set of a predetermined number of repetitions based on the participant’s 1RM from initial testing. Determination of predetermined number of repetitions is outlined below. Following the bench press exercise, an upper-body power task (three maximal effort PPU) was completed immediately following the PAP stimulus, in addition to 4- and 8- minutes post stimulus. All three PPUs were completed within the recovery period time frame. The conditions (10 and 20% of 1RM bench press) were implemented in a counterbalanced fashion among the three testing visits.

Determination of number of repetitions

Volume load (VL) is defined as the number of sets times repetitions (r) times the load lifted. For this study, the volume was matched based off the participant’s 80% 1RM and 5r volume. Thus, the volume load for the base calculation was the participant’s

$1\ RM \times .80\ (for\ 80\%) \times 5\ \div$weight at each intensity (10% and 20%). This equation determined the number of repetitions each participant completed at each intensity. For instance, if a participant had a 1RM of 100lbs, the volume for the 20% condition was calculated by the following: $100\ lbs \times .80 \times 5 \div 20lbs$, which equals 20r. The calculation was determined for each intervention and each participant.

Equipment

Trials were performed on a 600mm x 400mm force platform (Bertec, Inc., Columbus, Ohio, USA). The three variables found through this experiment were vertical ground reaction force (GRFz), normalized ground reaction force (nGRF), and rate of force development (RFD). GRFz was identified and calculated from kinetic data recorded during maximal effort PPUs from the force platform at a sampling rate of 1000Hz. Normalized GRF was found by dividing GRFz by body weight (N). RFD was calculated as the slope of the ground reaction force curve relative to the onset of concentric force production over 0-200 milliseconds.

Statistical Analysis

A 2x4 repeated measures analysis of variances (ANOVA) was utilized to analyze each dependent variable. Significant main effects or interaction identified through ANOVA were analyzed through Bonferroni post-hoc to reveal individual differences between conditions or interactions. All statistical analyses were obtained with SPSS 21 statistical software, and an alpha level of .05 was set as a priori.

RESULTS

The purpose of this study was to investigate the effects of PAP at two different loads (10% and 20%) of a given one repetition maximum (1RM) bench press on subsequent plyometric push-up tests. The secondary aim of the study was to determine the optimal recovery period to elicit PAP after the bench press exercise. The dependent variables observed during this experiment were ground reaction force, normalized ground reaction force, and rate of force development. No interaction or main effect was found for any variables. Figures 1-3 and Table 2 represent the data collected on the aforementioned variables.

Figure 1: Ground Reaction Force

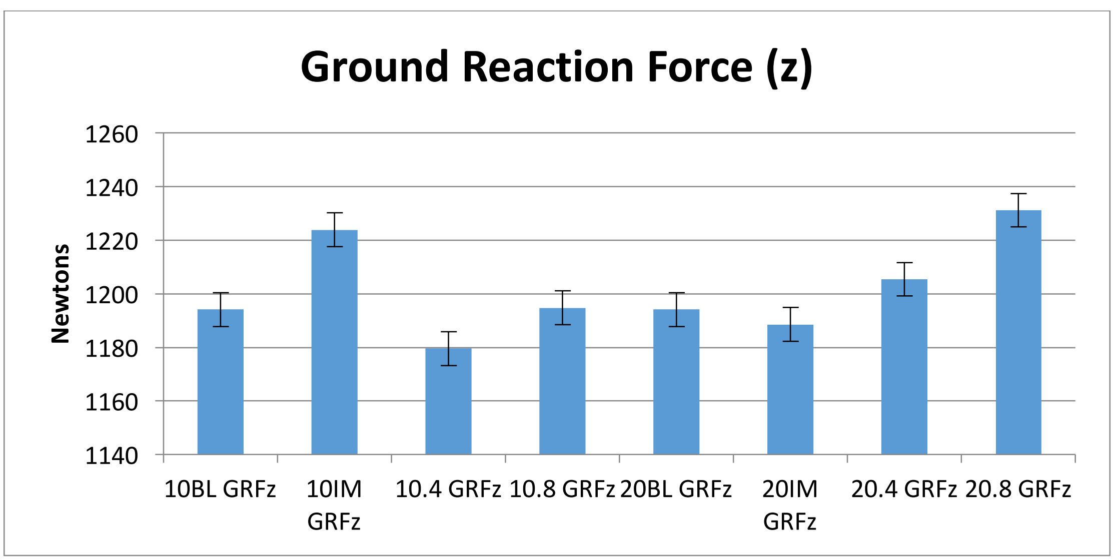

Figure 2: Normalized Ground Reaction Force

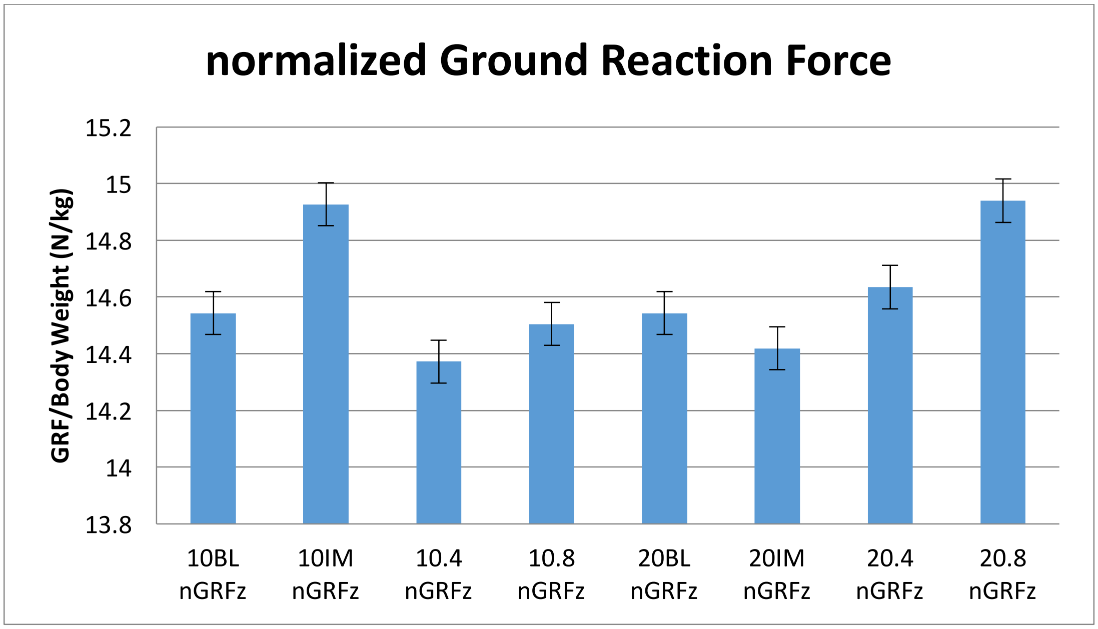

Figure 3: Rate of Force Development

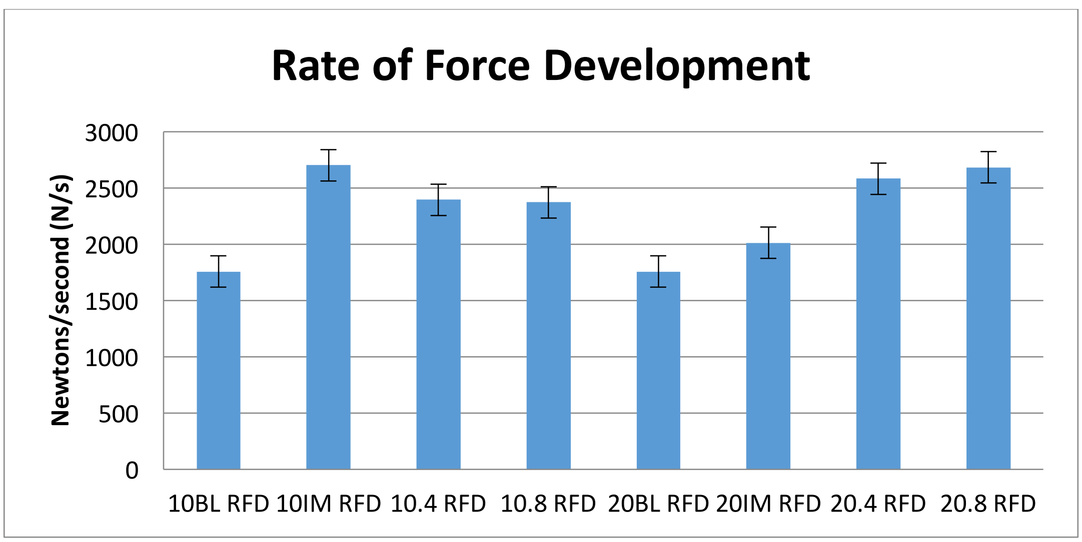

Table 2: Mean Data and Standard Deviation

Condition	**Ground Reaction Force**	**Normalized Ground Reaction Force**	**Rate of Force Development**
Baseline (10%)	1194.14 N ± 241.800	14.54 N/kg ± 3.007	1756.49 N/s ± 982.017
Immediately post (10%)	1223.89 N ± 355.258	14.93 N/kg ± 4.544	2704.01 N/s ± 2812.100
Four minutes (10%)	1179.58 N ± 255.570	14.37 N/kg ± 3.284	2396.58 N/s ± 1619.201
Eight minutes (10%)	1194.81 N ± 273.546	14.50 N/kg ± 3.469	2373.66 N/s ± 1602.071
Baseline (20%)	1194.14 N ± 241.800	14.54 N/kg ± 3.007	1756.49 N/s ± 982.017
Immediately post (20%)	1188.59 N ± 222.984	14.42 N/kg ± 2.818	2012.02 N/s ± 867.164
Four minutes (20%)	1205.50 N ± 253.628	14.64 N/kg ± 3.245	2584.18 N/s ± 1805.620
Eight minutes (20%)	1231.23 N ± 235.734	14.94 N/kg ± 2.999	2684.59 N/s ± 982.017

DISCUSSION

The purpose of this study was to observe the effects of PAP at two different loads (10% and 20% of a given 1RM bench press) on subsequent upper body exercises, such as plyometric push-ups, by examining GRFz, nGRFz, and RFD. This study also examined the time needed to elicit PAP, specifically looking at three time points: immediately post-stimulus, 4, and 8- minutes post-stimulus. The study examined potential interactions between these lifting conditions and rest times after the stimulus to see if there was an optimal condition. The results showed that performing a low load, high velocity (LLHV) warm-up before plyometric push-ups does not elicit a PAP response in any of the time points studied.

According to the PAP phenomenon, when a high-intensity specific warm-up, known as a conditioning contraction, precedes a similar exercise, the exercise performance is greater when comparing to a group who had not performed the warm-up (Gouvêa et al., 2013). This phenomenon has been displayed in many studies, including those to increase rate of force development and force production. The current results of this study do not match the previous findings with PAP research. A study conducted by Turner et al. (2015) found that sprint acceleration performance was enhanced after a warm-up of alternate-leg bounding. This study is similar to the present study because the researchers in the sprint study also hoped to find that PAP could be elicited after the incorporation of warm-ups that are more user-friendly (LLHV warm-ups). However, in the Turner et al. study, they were able to find increases in sprint performance after the

LLHV conditioning contraction, whereas the present study did not. Turner et al. (2015) included participants who had at least five years of plyometric training and even longer experience with sprint training. This is important to note because recreationally trained individuals seem to receive more benefits of PAP, which may suggest that the individuals in the present study were not as recreationally trained as they claimed to be.

Bullock and Comfort (2011) claimed that including depth jumps before a 1RM back squat exercise would increase the power output of that exercise. This study also included a LLHV conditioning contraction prior to a power exercise, and the Bullock and Comfort (2011) study produced significant findings in power production while the present study did not. However, the individuals in the depth jump study had been recreationally trained for a minimum of two years. Again, the level of recreational experience seems to play a role in the power output after PAP conditioning contractions.

In most of the previous literature, PAP has been elicited around 7 to 12 minutes post-conditioning contraction in recreationally trained individuals (de Assis Ferreira et al., 2012; Gouvêa et al., 2013; Turner et al., 2015). A meta-analysis revealed that the interval from 8-12 minutes may be an optimal recovery period between a conditioning contraction and JH (Gouvêa et al., 2013). These results have also been demonstrated in the explosive bench press, where a recovery period of 7 minutes was found to be optimal, and in 20-m sprinting exercises, where a recovery period of 8 minutes was optimal (de Assis Ferreira et al., 2012; Turner et al., 2015). However, the PAP phenomenon was not seen during any of the combination of conditions in this current study as the results have shown. After evaluating the data, several conclusions were drawn as to why PAP was not elicited after a low-load, high velocity conditioning contraction.

First of all, there were a few errors in data collection that were not initially noticed. When re-examining the initial data collection sheets, it was realized that anthropometrics were not collected from some participants. In turn, these subjects had to be excluded from data collection because we were unable to normalize their data because there was no mass collected at baseline. Also, during some of the subjects' testing, entire trials were not collected. This meant that data points were missing and more subjects were excluded from the final data set. While only 10 participants were needed to power the study, it would have been interesting to see if the inclusion of the rejected participants would have changed the results. Lastly, there wasn't a normalized period of time from when the data collection began on a trial and when the participant was to begin the plyometric push up (PPU). It was difficult to collect RFD because the time from beginning the PPU to peak force was different in every trial. If this time period had been regulated, the final results may have been different. These errors occurred primarily due to the fact that this was a pilot study, and there was a lack of attention to detail that would not have occurred if this was a later version of the same study. In order to get more reliable data, it would be necessary to standardize all of these practices.

Additionally, it is also possible that the conditioning contractions in this study did not actually meet the requirements to elicit a PAP response. While there was always an adequate recovery period in each condition, the initial warm-up may not have been great enough to elicit the intended response. By definition PAP is induced by a voluntary conditioning contraction performed at or near maximal intensity in order to induce a potentiation effect after a recovery period (Anthi et al., 2014; Hodgson et al., 2005). In most of the previous research, PAP has been induced during high-load, low velocity

(HLLV) conditioning contractions (Bullock & Comfort, 2011; Turner et al., 2015). In this study, low-load, high velocity conditioning contractions were employed because of their user friendly nature (Turner et al., 2015). Even though the same total volume of load was lifted during the conditioning contraction based on the equation $Volume\ Load = sets\ x\ repetitions\ x\ load\ lifted$, perhaps the near-maximal effort of traditional PAP conditioning contractions is what leads to the response being elicited.

Moreover, this study is only a part of a larger pilot study on low-load, high velocity PAP effects. This study only accounts for loads of 10% and 20% and for recovery intervals of baseline, immediately post-contraction, and 4- and 8- minutes post-contraction for upper body power. The larger study accounts for an additional load and four additional recovery periods and also includes lower body power. While the same results may occur in the large pilot study, it is important that research continues to see if the lack of significant results is limited to this study alone.

In total, there are a few conclusions to be drawn from this study. First, it is important to standardize all practices in the laboratory in order to see accurate results. Next, more research into the benefits of the maximal effort of PAP conditioning contractions should occur. There may be a greater tie to the maximal effort nature of those warm-ups than previously documented. Lastly, the full study on including more conditions and recovery intervals should not be overlooked. These variables could influence the data and show significant results that were not present in this small sampling of the full pilot study.

Further research should be conducted on the idea of LLHV conditioning contractions eliciting a PAP response equal to the responses elicited from HLLV conditioning contractions. In the future, it would be necessary to do prior research on the connection between volume load and near-maximal exercises to see if equal volume load can actually elicit equal responses. Lastly, further research in general on this topic would be beneficial because of the convenient nature of the LLHV warm-ups.

CONCLUSION

In conclusion, the results have shown LLHV conditioning contractions (10% and 20% of 1RM bench press) do not elicit a PAP response immediately post-contraction or 4- and 8-minutes post-contraction. Previous literature suggests that PAP is elicited between 7 and 12 minutes, and conditioning contractions were equal in volume load to loads in previous literature. However, the results of this study do not equal those of other studies. These discrepancies could be due to many conclusions including: errors in data collection, the inequality of LLHV contractions and HLLV contractions, the small sampling of a large study, or a combination of any of these conclusions. Ultimately, further research is required to fully understand the effects of LLHV conditioning contractions and total volume load.

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