THE EFFECTS OF A POSTACTIVATION POTENTIATION WARM-UP ON SUBSEQUENT SPRINT PERFORMANCE

by

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ABSTRACT

Postactivation potentiation (PAP) warm-ups have been proposed as a method for enhancing power. Few researchers have investigated the effects of PAP warm-ups on sprinting performance. The purpose of this study was to determine the effects of a PAP warm-up using sled resistance sprinting at different loads on subsequent unloaded sprints.

Twenty-four well-trained, anaerobically fit men and women, ages 18-28, participated in this study. They were assessed on vertical jump, cycling power, and body composition, and later, pretested in the 40 yd sprint on 4 nonconsecutive days prior to conducting a PAP warm-up that included a resistance sprint of either 0, 10, 20, or 30% of their respective body weight. Each resistance sprint was recorded for kinematic analysis. At the end of each PAP warm-up, a post-40 yd dash time was recorded.

A 2 x 2 x 4 factorial mixed ANOVA revealed a statistically significant difference between genders in 40 yd dash times ($p < .001$). A significant main effect difference was found in pre-and post-40 yd dash measures regardless of gender ($p < .001$). The results indicated that for the four resistance sled warm-ups tested, there were no significant differences in the post-40 yd dash times between loads, and the load by time interaction was not significant. The participants' 40 yd dash times improved 1.2% on average after the 10% load; for the unresisted sprint (0% load), and the 20% and 30% loads, the improvements were greater than 2% on average. Analyses of sprint kinematics demonstrated statistically significant differences in forward lean, hip flexion, and shoulder flexion between lighter and heavier loads (all *p's* < .05).

Even after significant disruptions in sprint mechanics, there appears to be a potential for heavier sled resistances to bring about acute improvements in 40 yd sprint performance; more so than 10% load. However, it may not be of greater benefit than warming up with 0% resistance. A replication of this study is needed, which includes but is not limited to: variations in sled load, recovery time, and additional interventions such as a PAP warm-up using squats, and a passive warm-up.

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CHAPTER 1

INTRODUCTION

Statement of the Problem

Athletes are always looking for training techniques that will give them a competitive edge. New training methods are continually being developed, or old methods are modified and recycled. Although many of these approaches to training have some practical merit, there is often little research evidence to scientifically support their effectiveness. Therefore, better designed and controlled research studies are warranted.

The warm-up is a training technique that needs further investigation. Although the effects of various warm-up protocols for a variety of sport activities are still being studied, additional research is needed to meet the specific warm-up needs for power athletes if optimal performance is to be achieved (Alves, Rebelo, Abrantes, & Sampaio, 2010; Andrews, et al., 2011; Chatzopoulos, et al., 2007; Gourgoulis, Aggeloussis, Kasimatis, Mavromatis, & Garas, 2003; Hilfiker, Klaus, Lorenz, & Marti, 2007; Kilduff, et al., 2007; Linder, et al., 2010; Matthews, Comfort, & Crebin, 2010). For example, several studies have suggested that stretching warm-ups, which have traditionally been used with endurance activities, may inhibit the execution of power activities (Behm, Button, & Butt, 2001; Church, Wiggin, Moode, & Crist, 2001; Fleck & Kraemer, 2004; Nelson & Kokkonen, 2001; Young & Elliot, 2001).

The observation that warm-up strategies utilized for endurance activities do not have a positive effect on performance in power activities has led to speculation that the ability to release large amounts of energy in a relatively short period of time, as is characteristic of power activities, may rely on different physiological warm-up mechanisms than endurance activities. Therefore, there is growing interest in developing warm-up strategies specific to power activities.

The aim of a warm-up for power activities generally includes improved maximal force, higher peak acceleration, and/or a faster rate of force development brought on through increased motor unit recruitment, increased activity of synergistic musculature, increased muscle spindle firing, reduced inhibition of the Golgi apparatus, and psychological effects; all of which are influenced either directly or indirectly by postactivation potentiation (PAP) (Hilfiker, et al., 2007; Xenofondos, et al., 2010). Warm-ups eliciting PAP may be the key to improved power performance.

PAP is defined as an enhanced neuromuscular state observed after the execution of a high intensity exercise (Robbins, 2005). The derivation of the PAP definition reflects the observation that an increase in muscle twitch contraction force follows a maximal or near maximal voluntary contraction. The increased muscle twitch force is thought to be due to an increase in myosin light chain phosphorylation making actin-myosin more sensitive to Ca^{2+} during subsequent contractions (Hodgson, Docherty & Robbins, 2005; Sale, 2002). Adaptations of reflex activity in the spinal cord, following execution of a high intensity exercise, are also hypothesized to contribute to the PAP response (Chiu et al., 2003; Gullich & Schmidtbleicher, 1996; Hamada, Sale, MacDougall, & Tarnopolsky, 2000; Scott & Docherty, 2004). In the whole human as opposed to an isolated muscle twitch, PAP does not increase muscle maximal force production, however, PAP does increase the rate of force development (Vandenboom, Grange, & Houston, 1993; Xenofondos, et al., 2010).

Because performance in power activities is a function of force application in a short period of time, increasing the rate at which a muscle develops force should translate into improved performance of the power activities. In other words, if high intensity power activities are conducted while the muscles are in a potentiated state, there is a likelihood of improved performance. For example, stride length and stride rate, two primary factors influencing speed development, may be enhanced through the improved rate of force development that accompanies PAP.

In order to maximize PAP, appropriate warm-up strategies are needed. Typically a PAP warm-up begins with 3-5 minutes of dynamic activities performed at moderate intensities. These dynamic activities are followed by a movement performed at maximal or near maximal intensity (PAP movement). The PAP movement should also be biomechanically similar to the power performance movement. Following the PAP movement, a short rest period is required for replenishment of high energy phosphates, before performing the power activity. Some research has indicated that if biomechanically similar PAP movements are used as part of the warm-up, performance of the power activity is enhanced, possibly due to the enhanced neuromuscular PAP state (Baker, 2003; Baker, Nance, & Moore, 2001; Chatzopoulos, et al., 2007; Gourgoulis, et al., 2003; Linder, et al., 2010; Matthews, et al., 2010; Mitchell & Sale, 2011; Weber, Brown, Coburn, & Zinder 2008; Young, Jenner, & Griffiths, 1998).

A common PAP warm-up seen in the research literature is as follows: a moderate intensity dynamic warm-up including 4 minutes of cycling and/or 1 set of squats; followed by a max/near max squat (PAP movement); then, after a short rest period allowing for phosphocreatine resynthesis, the power activity is executed (e.g., vertical jump measurement; Chatzopoulos, et al., 2007; Gourgoulis, et al., 2003; Linder, et al., 2010; Matthews, et al., 2010; Weber, et al., 2008).

Although some researchers have demonstrated that PAP warm-ups resulted in improved muscle performance, others have failed to demonstrate this relationship (Chiu, et al., 2003; DeRenne, 2010; Hanson, Leigh, & Mynark, 2007; Till & Cooke, 2009). A number of factors have been proposed to account for the inconsistency in the PAP warm-up research literature, including: variability in the conditioning background of the individuals performing the exercises, muscle fiber composition of the individuals, intensity of the PAP warm-up, and the rest period between the warm-up and power activity.

Although significant improvements in performance have been found among participants with a variety of conditioning backgrounds, the research suggests that a PAP warm-up effect is more likely if well-trained, anaerobically fit individuals rather than recreationally fit athletes are observed (Chiu, et al., 2003; Gourgoulis, et al., 2003; Young, 1993). The difference in the PAP warm-up effect between the well-trained and recreationally trained athletes may reflect an increased ability of well-trained athletes to recruit more motor units, with greater synchronicity, and at a higher firing rate during the PAP movement, than individuals with less training background (Ratamess, 2008; Schmidtbleicher & Buehrle, 1987).

Increases in performance with a PAP warm-up also seem to be dependent upon muscle fiber composition. Humans and small animals with a higher percentage of fast twitch or type II muscle fibers demonstrate greater PAP responses than humans and small animals with higher percentages of slow twitch or type I muscle fibers (Hamada et al., 2003; Houston, Lingley, Stuart, & Grange,1987; Moore & Stull, 1984;Vanderboom & Houston, 1996; Xenofondos, et al., 2010). For humans, it is also possible that athletes with higher percentages of type II fibers experience more success in power events and, therefore, spend more time training to further enhance their performance in power activities; thus accounting for the tendency for more training background to positively influence the performance of the power exercise that follows the PAP movement.

Considerable research has also focused on studying the influence of the relative intensity of the PAP warm-up. Vandervoort, Quinlan, and McComas (1983) analyzed the effect of conditioning voluntary contractions (VC) of different intensities and durations on twitch potentiation in human plantar flexor muscles. The authors concluded that VCs of less than 75% maximal voluntary contraction (MVC) produced little or no potentiation and that MVCs lasting 5–to 10-seconds caused the greatest twitch potentiation (Vandervoort et al., 1983). Requena, Gapeyeva, Garcia, Ereline, and Paasuke (2008) observed similar results. They investigated twitch potentiation after voluntary versus electrically induced isometric contractions in human knee extensor muscles. The researchers found that a voluntary isometric contraction of knee extensor at 25% of MVC was not enough of a stimulus to induce twitch potentiation. They also found that twitch potentiation was significantly increased immediately after the MVC trial only, supporting the notion that the greatest PAP effects are likely to be found after maximal, or near maximal muscle contractions.

Another important factor influencing the PAP warm-up response is recovery time. The time between the PAP warm-up and the subsequent power activity is the recovery time. The challenge is to select a time that is long enough to allow for the effects of fatigue to dissipate without losing the potentiation or PAP effect (Hodgson et al., 2005; Weber et al., 2008). If fatigue is too great, such as immediately after the PAP movement, then PAP cannot have optimal effects (Robbins, 2005). If too much time passes, fatigue is lessened, but so are the effects of PAP. Several studies have examined the impact of different recovery times on performance of the power activities. These studies have found positive impacts on performance of power activities with recovery periods ranging from 0 to 20 minutes (Bevan, et al., 2010; Comyns, et al., 2006; Docherty, Robbins, & Hodgson, 2004; Gullich, & Schmidtbleicher, 1996; Kilduff, et al., 2007).

An appropriate rest period following a PAP warm-up may also be dependent upon the activities involved. For example, Linder, et al. (2010) found improvements in 100 m sprint times after participants were given 9 minutes of recovery time. The recovery time was preceded by a 4 RM squat. Other studies looking at the effects of PAP warm-up on 30 meter (m) and 40 m sprinting distances, used a 4-to 5-minute recovery time (Chatzopoulos, et al., 2007; McBride, Nimphius, & Erickson, 2005). These studies also used a heavy weight squat as the PAP movement in the warm-up. It may be that because the distances of the sprints were shorter (30 m-40 m vs. 100 m) less recovery time was necessary. More research is needed regarding PAP warm-up intensity and recovery time.

Although several researchers have examined the PAP warm-up concept, many of the studies have involved exercises like squats and vertical jumps, rather than focusing on competitive events like sprinting. The studies that have examined a PAP warm-up and sprinting involve numerous types of sprinting and are summarized in Table 1. The studies that have demonstrated a significant effect of a PAP warm-up on sprint performance have: (a) used a rest period of 4-10 minutes; (b) used heavy weight squats as

Table 1

PAP Sprint Studies

Authors	**Participants**	**Pre-load warm-up activity**	**Rest interval**	**Results**	**Participants**
McBride, Nimphius, & Erickson, 2005	Football Players	90% 1 RM Squats	4 mins.	0.87% ($p \leq .05$) improvement in 40 m sprint compared to other warm-ups	Football Players
Chatzopoulos, et al., 2007	Amateur Athletes	90% 1 RM Squats	5 mins.	improvement ($p \leq .05$) in 30 m sprint	Amateur Athletes
Matthews, Matthews, & Snook, 2004	Rugby Athletes	5 RM Squat	10 mins.	improvement ($p < .0001$) in 20 m sprint	Rugby Athletes
Linder, et al., 2010	Recreational Female Athletes	4 RM Squat	9 mins.	0.19 s ($p < .05$) improvement in 100 m sprint	Recreational Female Athletes
Matthews, Comfort, & Crebin, 2010	Ice Hockey Players	Resistance Sprint	4 mins.	2.6% decrease ($p = .002$) 25 m sprint times	Ice Hockey Players

warm-up activity to elicit PAP; and (c) used either well-trained or recreationally fit participants (see Table 1 for a summary of relevant research).

One of the studies listed in the table is very unique, in that it demonstrated the effects of a resistance sprinting warm-up on subsequent sprints (Matthews, et al., 2010). The researchers in this study reported significant improvements in 25 m sprint times. However, the study was conducted with ice-hockey players, using an ice rink as the testing surface. No one has examined the use of resistance sprinting warm-up with other populations on other sprint surfaces, such as a track. If using a resistance sled as part of a PAP warm-up for track sprinters results in faster sprint times, the resistance sled could serve as a feasible and accessible PAP warm-up for sprinting. The warm-up also may provide a training method using a device (resistance sled) that is more biomechanically similar to sprinting than a squat, which has typically been used.

Purpose of the Study

Therefore, the purpose of this study was to examine the influence of a PAP warm-up protocol (resistance sled) on subsequent sprint performance in well-trained, anaerobically fit individuals. Specifically, this study was aimed at determining the effects of sled resistance sprinting at different loads on subsequent unloaded 40 yd sprints.

Significance of the Study

It is clear that there is a strong potential for a PAP warm-up to bring about improvements in acute power performance. From a practical standpoint, the improvements in speed, jumping ability, and agility may have a positive impact in competitive situations. Linder, et al. (2010) put this into perspective when discussing the findings of their study, which involved observing the effects of a PAP warm-up on 100 m dash performance. They found that the warm-up improved 100 m times by 0.19-seconds in recreationally fit college-aged females. When discussing these findings the researchers noted that in the 2004 Olympics, there was a difference of 0.04 seconds between the top three finishers in the Women's 100 m dash final. Further, there was a difference of 0.030 - 0.1 seconds between third and sixth place finishers. In other words, small differences separate the best sprinters and so a small PAP effect might have a practical impact on race results (Linder, et al., 2010). The potential for a practical impact on performance of a power activity is even more apparent if the results of the 2011 Utah High School 5A 100 m state final times are used. The difference between first and third place for the women was 0.17 seconds, whereas the difference between first and third place for the men was 0.16 seconds. The final top three times for the men's 100 m in Utah 5A are typically just under 11 seconds (e.g., 10.9 seconds) while for the women the top three times are in the low 12 second range (e.g., 12 seconds). Therefore, a 0.19 second difference in finish time (or approximately a 1.65% improvement) would have had an impact on the final placement standings.

Not only might individuals competing in the 100 m see a benefit from a PAP warm-up, but athletes participating in many other activities where lower body power is required may benefit; examples include: a football player completing a pro-agility test, or 40 yd dash; a basketball player testing on vertical jump; and, a long jumper preparing for competition.

The findings of this study may meaningfully add to the limited amount of literature on the PAP warm-up, and potentially lead to an increased understanding of effective warm-ups for enhancing the performance of power activities.

Limitations

The following limitations were recognized for this study:

1. The population used in this study was a nonprobability sample. Participants were recruited based on availability and convenience, but also because they possessed characteristics that were important for this study. The sample used for the study were well-trained, anaerobically fit, college students located in the Southwestern region of the United States.
2. The participants may not be representative of the total population of college students with this particular conditioning background.
3. The methods used in this study for determining type II muscle fibers were indirect.
4. The recovery period between the PAP warm-up and subsequent power activity was 4 minutes, and may not be as effective as other recovery time periods.

Delimitations

The following delimitations applied for this study:

1. The study was delimited to college-age students in one geographic region, limiting its generalizability to this population throughout the United States.
2. The study was delimited to one specific PAP warm-up protocol.

Assumptions

This study was conducted under the following assumptions:

1. It was assumed that the participants accurately represented a normal population of well-conditioned, anaerobically fit male and female college students.
2. It was assumed that the participants understood the questionnaire and provided honest and accurate responses.
3. It was assumed that the participants understood the assessment protocol and that they gave their maximal effort while participating.

Aims and Research Hypotheses

The primary aim of this study was to examine the influence of a PAP warm-up protocol on subsequent sprint performance in well-trained, anaerobically fit individuals. Specifically, this study aimed to determine the effects of a 20 yd sled resistance sprint at different loads on subsequent 40 yd sprint performance without resistance. It was hypothesized that the resistance sprinting warm-up protocols would elicit a PAP effect and have a statistically, and practically significant impact on subsequent sprinting performance. For this study, practical significance was defined as a 1.65% improvement.

It was also hypothesized that men would have faster 40 yd sprint times than women in this study, and there would be no interaction effect between genders and sled load.

Finally, it was hypothesized that the 10% body weight sled load warm-up would represent the best balance between a PAP effect and fatigue recovery, and therefore result in the greatest improvements in sprint performance when compared to the other sled loads. The hypothesis that 10% body weight is an optimal sled load was based on the assertion that loads heavier than 10-15% can cause significant disruptions in sprint technique (Lockie, Murphy, & Spinks, 2003).

Definition of Terms

Plyometrics

Plyometrics are defined as quick, powerful movements involving the stretch shortening cycle (Potach & Chu, 2008). Examples of activities involving this cycle are jumping, sprinting, and agility drills. Plyometrics have been consistently proven to increase muscle force and power (Hewett, Stroupe, Nance, & Noyes, 1996; Radcliffe & Osternig, 1995). They were used in the Soviet Bloc prior to the 1970s, and Yuri Verkhoshansky is generally given credit for introducing the technique (Verkhoshansky & Tatyan, 1973). Plyometrics, also called “shock training” is a combination of Greek words. The literal interpretation is to increase measurement (*plio*-more; *metric*-measure). The concept was introduced in America by Olympian Fred Wilt (Wilt, 1975).

Postactivation Potentiation (PAP)

PAP is referred to as an enhanced neuromuscular state observed immediately after high intensity exercise, bringing an increase in muscle twitch contraction force following a maximal or near maximal voluntary contraction. PAP is likely due to an increase in myosin light chain phosphorylation making actin-myosin more sensitive to Ca^{2+} during subsequent contractions and adaptations of reflex activity in the spinal cord (Chiu, et al., 2003; Gullich & Schmidtbleicher, 1996; Hamada, et al., 2000; Robbins, 2005; Scott & Docherty 2004).

Resistance Sled

A resistance sled is a device commonly used for increasing strength and power; its design allows for weights to be easily secured or removed in order to adjust the degree of resistance; additionally, the device consists of a metal sled traveling on two parallel metal tubes; a nylon rope and harness are attached from the sled to an athlete for towing (Power Systems Inc., Knoxville, TN; Alcaraz, Palao, Elvira, & Linthorne, 2008; Brown, Ferrigno, & Santana, 2000; Foran, 2001; Lockie, Murphy, & Spinks, 2003; Mann, & Herman, 1985).

Stretch-Shortening Cycle

The Stretch-Shortening Cycle occurs in the muscle, when the sequence of eccentric to concentric actions is performed *quickly*, the muscle is stretched slightly before the concentric action, hence the term "stretch shortening"; the muscle is stretched slightly and then shortens. The slight stretching stores elastic energy, and the resultant concentric action is more powerful than if the slight stretch did not occur. Although synonymous with the term plyometrics, some researchers maintain that the stretch-shortening cycle term may be more appropriate for describing body weight jumps and medicine ball throws, whereas plyometrics should be used to describe weighted jump squats and bench pressing in which the bar is thrown throught the air (Fleck & Kraemer, 2004).

CHAPTER 2

REVIEW OF RELATED LITERATURE

This review of literature examined the effects of PAP warm-up protocols on lower body power and sprint performance. The shortcomings of stretching warm-ups are considered, and the inconsistencies in the PAP research literature are discussed in greater detail.

Since the 1970s, there has been a growing body of evidence suggesting that stretching may inhibit performance in power activities (Fleck & Kraemer, 2004). The negative effects are particularly evident as a result of static stretching. Young and Elliot (2001) found that after static stretching, there was a significant decrease in drop jump performance. These researchers also speculated that static stretching may have a detrimental effect on short, stretch-shortening cycle muscle functions (e.g., jumping with an approach; the contact phase in sprinting, etc.).

In a meta-analysis conducted by Simic, Sarabon, and Markovic (2012), it was concluded that the effects of static stretching were most detrimental to the rate of force development, and also, to a lesser extent, negatively impacted jumping, sprinting, and throwing--all of which are characteristic of power activities. The researchers in the Simic et al. (2012) meta-analysis recommend avoiding the use of static stretching as a sole warm-up activity.

In addition to static stretching, other types of stretching may inhibit power performance. Church, et al. (2001) found that proprioceptive neuromuscular facilitation stretching negatively affected vertical jump performance in women. Another study conducted by Nelson and Kokkonen (2001) demonstrated that ballistic stretching may inhibit maximal strength. Although strength and power are not the same, strength is a component of power, and as such, a decrease in strength may lead to a decrease in power.

Behm, et al. (2001) suggested that the decrements in performance resulting from a stretching warm-up may be related to muscle inactivation affected by the stretch rather than changes in the elasticity of musculo-connective tissue components. At any rate, research on the use of stretching as a warm-up indicates that it may not be appropriate for power athletes.

Postactivation Potentiation (PAP) warm-up protocols may be the key to improving performance in power activities (Baker, 2003; Baker, et al., 2001; Chatzopoulos, et al., 2007; Gourgoulis, et al., 2003; Linder, et al., 2010; Matthews, et al., 2010; Mitchell & Sale, 2011; Weber, et al., 2008; Young, et al., 1998).

Despite the research supporting the notion that PAP warm-ups may improve power performance, there are several inconsistencies in the PAP research that may be explained as a result of the following factors: variability in the conditioning background of the individuals performing the exercises, muscle fiber composition of the individuals, intensity of the PAP warm-up, the rest period between the warm-up and power activity, and the PAP movement of the warm-up (Bevan, et al., 2010; DeRenne, 2010; Docherty, et al., 2004; Kilduff, et al., 2007; Xenofondos, et al., 2010).

Conditioning Background

Much of the existing literature suggests that conditioning background plays a role in affecting the degree of PAP. Specifically, elite athletes will likely experience a greater improvement in performance than recreationally fit athletes, if a PAP effect is present (Chiu, et al., 2003; Gourgoulis, et al., 1996; Young, 1993). The differences may be attributed to the ability of well-trained athletes to recruit more motor units, with greater synchronicity, and at a higher firing rate, than individuals with less training (Ratamess, 2008; Schmidtbleicher, & Buehrle, 1987). Additionally, individuals with a stronger conditioning background are likely to have a higher percentage of lean mass, which has been strongly correlated with speed and power development (Miller, White, Kinley, Congleton, & Clark, 2002).

Despite the evidence that well-trained athletes are more likely to benefit from PAP warm-up protocols, the results of some studies illustrate that individuals of a variety of conditioning backgrounds may still see improvements in performance. Batista and colleagues found no differences when comparing PAP response among power-track and field athletes, bodybuilders, and “physically active subjects” (Batista, Roschel, Barroso, Ugrinowitsch, & Tricoli, 2011). They concluded that an individual’s level of maximal dynamic strength training background had no influence on the manifestation of PAP. These researchers also indicated that the differences in PAP effect may be individual rather than just sport specific and specific to training level (e.g., muscle fiber type). Linder, et al. (2010) found significant improvements in 100 m times in recreationally fit college females as a result of a PAP warm-up. The results of this study also suggested that it is not necessary for individuals to be well-trained athletes for power performance to be enhanced.

Muscle Fiber Type

Besides conditioning background, another factor that appears to play a role in the magnitude of PAP response is the amount of fast twitch type II muscle fibers (Xenofondos, et al., 2010).

In studies with humans and small mammals, it has been revealed that individuals with a higher percentage of muscle containing type II fibers demonstrated greater PAP response (Hamada, et al., 2000; 2003; Houston, et al., 1987; Moore, & Stull, 1984; Vanderboom & Houston, 1996). The reason for this is type II fibers produce a greater amount of myosin light chain phosphorylation in response to intense physical activity, making actin-myosin more sensitive to calcium during subsequent contractions (Moore & Stull, 1984; Zhi et al., 2005).

In regard to an individual's ability to generate speed, muscle fiber type plays a significant role. In a classic study, Costill et al. (1976) demonstrated that sprinters had a significantly greater amount of type II fibers than distance runners and untrained individuals. The advantage of a higher percentage of type II muscle fiber allows for one to produce greater amounts of force in a shorter time period (Cissik, 2004). In essence, a higher percentage of fast twitch type II fibers may translate into a greater ability to generate speed and a greater PAP response.

Intensity of the PAP Warm-up

Considerable research has also focused on studying the influence of the relative intensity of the PAP warm-up. Vandervoort et al. (1983) analyzed the effect of conditioning voluntary contractions (VC) of different intensities and durations on twitch potentiation in human plantar flexor muscles. The authors concluded that VC's of less than 75% maximal voluntary contraction (MVC) produced little or no potentiation and that MVCs lasting 5–10 seconds caused the greatest twitch potentiation (Vandervoort et al. 1983). Requena et al. (2008) reinforced these findings. They investigated twitch potentiation after voluntary versus electrically induced isometric contractions in human knee extensor muscles. The researchers found that a voluntary isometric contraction of knee extensor at 25% of MVC was not enough of a stimulus to induce twitch potentiation. They also found that twitch potentiation was significantly increased immediately after the MVC trial only. This supports the notion that the greatest PAP effects are likely to be found after maximal, or near maximal muscle contractions.

Recovery Time

Another important factor influencing PAP is recovery; specifically, the recovery time between the warm-up and subsequent physical activity. Finding the appropriate recovery time is challenging because fatigue can coexist with PAP, and may attenuate the exploitation of PAP (Hodgson, Docherty, & Robbins, 2005; Weber, et al., 2008). If fatigue is too great, such as immediately after the warm-up activity, then PAP cannot have optimal effects (Robbins, 2005). If too much time passes, fatigue is lessened, but so are the effects of PAP. Essentially, time must be provided to replenish high energy phosphates, but if too much time is provided, twitch potentiation may not be significant enough to bring about the desired effects on power performance.

Several researchers have examined the effects of different rest periods on PAP. These studies have found a PAP effect ranging from 0 to 20 minutes post-warm-up (Bevan, et al., 2010; Comyns, et al., 2006; Docherty, et al., 2004; Gullich, & Schmidtbleicher, 1996; Kilduff, et al., 2007).

Using rugby athletes as participants, Bevan, et al. (2010) investigated the effects of PAP on 10 m sprints (with a 5 m split), using one set of three repetitions of back squat at 91% of 1 RM as a warm-up. The participants ran a 10 m sprint after rest periods of baseline, 4, 8, 12, and 16 minutes. The authors of the study found no significant time effect over the duration of the study.

Another study conducted with rugby players produced results that brought up additional questions about the optimal rest duration (Kilduff, et al., 2007). Participants in the study were evaluated on peak power output being given intracomplex rest intervals of 15 seconds, 4, 8, 12, 16, and 20 minutes. The researchers used a high intensity resistance training warm-up. When allowed 12 minutes rest, the participants' peak power output increased by 8% for the upper body tests, and 4.5% for the lower body. Based on their findings, the researchers came to the conclusion that 8-12 minutes is an appropriate recovery time for enhancing muscular performance. One problem with the Kilduff, et al. (2007) study is that the varied rest intervals were tested on the athletes during the same training session. It is reasonable to assume that this may have had some effect on PAP. Had the researchers measured the effects of each individual rest period in separate testing sessions the results might have been different.

Kilduff, et al. (2011) would later conduct another study with other researchers on rest intervals with international sprint swimmers. This study investigated the effects of PAP on swimming starts using rest periods of 15 seconds, 4, 8, 12, and 16 minutes. The researchers found that the greatest power output and jump height was achieved after 8 minutes of recovery.

Using the 8-to 12-minute recommendation for recovery from Kilduff, et al. (2007; 2011), Linder and colleagues (2010) found a significant improvement in 100 m sprint times for female track athletes. The athletes participated in two testing sessions. The first session used a 4-minute standardized warm-up on a stationary bike, followed by 4 minutes of active rest, a 100 m track sprint, followed by another 4-minute active rest period, finishing with a second 100 m sprint. The second session was the same only, after the first 100 m sprint, there was a 4-minute active rest period followed by a 4 RM squat warm-up. Then the participants rested 9 minutes (following the 8-to-12-minute protocol recommended by Kilduff, et al., 2007), which was followed by a final 100 m sprint. These times were significantly faster than when the participants did not have the 4RM squat warm-up. One question that does, however, come to mind when examining these results is: would a longer rest period be necessary for longer, more strenuous activities such as a 100 m sprint, and shorter rest periods be appropriate for activities such as a vertical jump test or 40 yd dash? Further research is needed in regard to this.

A large number of studies have used between 2 and 5 minutes as a rest period between the PAP warm-up and the subsequent power activity. Many of the studies using the 2-to 5-minute rest period have followed the recommendations of Gullich and Schmidtbleicher (1996). McBride, et al. (2005) found a significant improvement in 40 m dash sprint performance 4 minutes after participants conducted a heavy-load squat warm-up. Chatzopoulos, et al. (2007) found an increase in 30 m dash running speed 5 minutes after amateur athletes performed heavy load squats. The researchers in this study also looked at the effects of a 3 -minute rest period but found no significant improvement.

Smith, Fry, Weiss, Li, and Kinzey (2001), at the University of Memphis, measured the effects of PAP on a 10-Second Sprint Cycle Test. A 5-minute rest was given to participants after performing squats at varied weights (40-90% 1 RM). Acute performance was enhanced by following the PAP warm-up protocol, more so than those without a high intensity resistance exercise that preceded the test, and more than those who were given a 20-minute recovery after performing the squats.

Weber, et al. (2008) found an increase in squat jump performance after 5 repetitions at 85% of 1 RM back squats and 3-minutes of rest. Mitchell and Sale (2011) also found an increase in jump performance (counter-movement jumps), following a 5 RM squat and 4 minutes of rest.

McCann and Flanagan (2010) investigated the effects of PAP on vertical jump performance. They compared the effects of a 4-minute and 5-minute recovery among division I volleyball athletes. The results of their study indicated that there were no significant differences between the two rest periods and that coaches would be wise to address the individual effects of PAP on their athletes in determining an appropriate rest interval.

PAP Movement

Another important aspect of the PAP warm-up is the type of high intensity exercise (PAP movement) used in the warm-up. Previous research has indicated that if the PAP movement is biomechanically similar to the subsequent power activity, performance may be enhanced (Chatzopoulos, et al., 2007; Linder, et al., 2010; Matthews, et al., 2010; Robbins, 2005).

The majority of the research on PAP warm-up for improving short-term lower body power has used a squat as the PAP movement (Docherty, et al., 2004; Gourgoulis, et al., 2003; Linder, et al., 2010; McBride, et al., 2005; Radcliffe, & Osternig, 1995; Radcliffe & Radcliffe, 1996; Weber, et al., 2008). In other studies, a plyometric exercise was the PAP movement used. Hilfiker et al. (2007) found that after a PAP warm-up that included drop-jumps, elite athletes saw acute increases in jump height and maximal power. In addition to squat and plyometrics, a few studies have also found a significant effect when using a hang clean or snatch as the PAP movement (Andrews et al., 2011; McCann & Flannagan, 2010; Radcliffe & Radcliffe, 1996).

These studies have primarily examined the effects of a PAP warm-up on measures such as vertical jump performance, rather than focusing on competitive events such as sprinting. Whether or not a PAP warm-up protocol can be used in competitive settings, such as sprinting, needs to be studied more closely. Those studies that have demonstrated a significant effect on sprint performance as a result of a PAP warm-up were summarized in Table 1 (see page 7). The studies that have demonstrated a significant improvement have: (a) used a rest period of 4-to 10-minutes, (b) used heavy weight squats as warm-up activity to elicit PAP, and (c) used either well-trained or recreationally fit participants (see Table 1 for a summary of relevant research).

As was mentioned in Chapter 1, only one of the studies addressing the effects of PAP warm-ups on sprint performance used a resistance sprint (Matthews, et al., 2010). The researchers in this study found significant improvements in 25 m sprint times as a result of the resistance sprint warm-up. However, there were some limitations in the study. The limitations were that the study was conducted with ice-hockey players, using an ice rink as the testing surface, and they did not clearly gauge the amount of resistance given for the resistance sprints in the warm-up. Whether these effects can be found in other populations on other sprint surfaces, such as a track, is unclear and needs to be studied. Additionally, there are questions remaining on whether different levels of resistance had different effects on sprint performance. Testing this resistance sprinting warm-up while using a sled allows for determining levels of resistance, in a way that is biomechanically similar to sprinting. A sled also may be more feasible and accessible if needed prior to competition. Also testing the warm-up with a population besides hockey players on a track surface can provide a better understanding of how the warm-up can benefit a wider variety of individuals.

Conclusion

Although there are many questions regarding this topic, which needs to be elucidated, this review of literature identified some specific issues relating to PAP. Some of these issues included variability in the conditioning background of the individuals performing the exercises, muscle fiber composition of the individuals, intensity of the PAP warm-up, the rest period between the warm-up and power activity, and the PAP movement of the warm-up. The purpose of this study was to determine the effects of sled resistance sprinting at different loads on subsequent sprinting performance without resistance, in well-trained, anaerobically fit, males and females.

CHAPTER 3

METHODS

This chapter describes the participant selection criteria, the instrumentation and measures, the methodological procedures, and the statistical analyses used to address the purposes of the study.

Participants

An a priori power analysis was conducted indicating that approximately 24 participants were needed for this study (Matthews et al., 2010). The literature on PAP suggests that this phenomenon is seen in humans regardless of gender (Ebben, Jenson, & Blackard, 2000; Jensen, & Ebben, 2003; Xenofondos, et al., 2010). Therefore, both males and females were recruited for this study.

Preliminary studies also suggested that anaerobically well-trained individuals may be more likely than untrained participants to exhibit a PAP response when challenged with high intensity exercise (Chiu et al., 2003; Gourgoulis et al., 2003; Gullich & Schmidtbleicher, 1996; Young, 1993). The participants in this study were trained, anaerobically fit men and women, aged 18-28, from a university in the Southwestern United States. For the purposes of this study, being anaerobically trained was defined as having participated in exercise activity 4-6 days per week, for 60 -minutes per session, with 75% of those activities requiring muscular power, for the past 6 months.

The participants were required to complete one questionnaire constructed by the principal investigator. The first portion of the questionnaire included questions to determine the physical readiness of each individual to participate in the study, and the second portion included questions regarding nutrition and supplement intake. The questionnaire was primarily used as a screening tool. All participants needed to be free of injury for the past 6 months, and commit to abstain from additional lower-body resistance training during the study period. Participants were excluded if they had taken ergogenic aids (e.g., anabolic steroids, growth hormone, or any related performance-enhancing drugs). Participants were allowed to continue with the study if they were taking, or had previously taken, any vitamins, or mineral supplements (the questionnaire can be found in Appendix A).

Instrumentation

Sprint Timing

Testing was performed on a Mondo indoor track (Mondo USA, Lynnwood, WA). Sprint times were measured by a multi function infrared timing system (Lafayette Instrument Company, Lafayette, IN, USA). For this study, photo cells were set up to record times at 10, 20, 30, and 40 yds.

Sled

A weighted sled, which was attached to the participant by dual 3.17 m (10 feet, 5 inches) leads and a waist harness, was used for this study (Titan Global Trading). The waist harness was used as opposed to a shoulder harness to avoid excessive forward lean by the participants (Alcaraz et al., 2008; Mann, & Herman, 1985). The sled consisted of a 15.2 cm (6 in.) long, 2.5 cm (1 in.) diameter metal post which was secured upright to a 25.4 x 31.8 cm (10 x 12.5 in.) metal plate. Both the metal plate and post traveled on two metal parallel metal tubes that were approximately 59.7 cm (23.5 in.) long, and 2.5 cm (1 inch) in diameter. The sled weighed 2.45 kg (5.4 lbs.) and the harness weighed 0.27 kg (0.6 lbs.; Titan Global Trading). Sled towing is a common practice used in resisted sprint training, and has the benefit of being unaffected by wind, as is the case with other resistive devices such as parachutes (Lockie et al., 2003). Its design allows for weights to be easily secured to or removed in order to adjust the degree of resistance. Its use in training as a method of improving stride length and power has increased in popularity, as illustrated by a number of publications (Alcaraz et al., 2008; Brown et al., 2000; Foran, 2001; Lockie et al., 2003).

Body Compostion Testing

Body composition testing was conducted using an Air Displacement Plethysmography Technique (BOD POD; COSMED, Rome, Italy; Heyward & Wangner, 1996). Testing/assessments of body composition were conducted in the Human Performance Lab at Weber State University. The BOD POD technology is fundamentally the same as underwater (hydrostatic) weighing, but uses air displacement instead of water displacement. The BOD POD measures the volume of air a person’s body displaces while sitting inside a chamber. By using air instead of water, the BOD POD offers a fast, safe, and easy-to use tool for measuring body composition (body fat percentages), without sacrificing accuracy. The participants were required to wear a swimsuit and swim cap during the test. This minimized errors caused by air trapped in clothing and hair. First, participant height was measured to the nearest 0.1 cm and body weight was measured to the nearest 0.01 kg on a calibrated electric scale with the participant wearing only a tight fitting swimsuit. Next, the participant sat comfortably inside the BOD POD chamber while computerized pressure sensors determined the amount of air displaced by the person's body so that body density could be calculated. The body fat percentage was calculated using Siri's (1961) equation. For each participant, three measurements were completed and averaged to determine body composition. BOD POD Testing is highly accurate, safe, and quick, with a complete analysis in about 3 to 5 -minutes. Previous research findings suggested the BOD POD between day test-retest reliability to be high (*rtt* = .91-.96), and valid when using hydrostatic weighing as the criterion measure ($r^2 >$ .80; Demerath, Guo, Chumlea, Towne, & Siervogel, 2002; Frisard, Greenway, & Delany 2005; McCrory, Gomez, Bernauer, & Mole, 1995; Miyatake, & Nonaka, 1999). The Bod Pod provided information on lean body mass which is a factor relating to speed development (Miller et al., 2002).

Inertial Load Cycling

Inertial Load Cycling Test was conducted using a Monark ergometer (Varburg Sweden, Model 818). The Inertial Load Cycling Test has a very strong correlation with lean thigh volume and provides an indirect measure of type II muscle fiber (Hautier, Linossier, Belli, Lacour, & Arsac, 1996; Martin, Wagner, & Coyle, 1997). Both muscle fiber type and lean mass play an important role in speed production. The test involved participating in four bouts of maximal acceleration cycling. Each bout lasted 3-4 seconds and there was 2 minutes of rest between cycling bouts. Two sessions of familiarization were conducted before a third session which was used as the official testing day. The

Inertial Load Cycling test has been found to be an internally consistent, reliable tool for measurement (ICC = .99; r^2 =0.999; Martin, et al., 1997).

Vertical Jump Testing

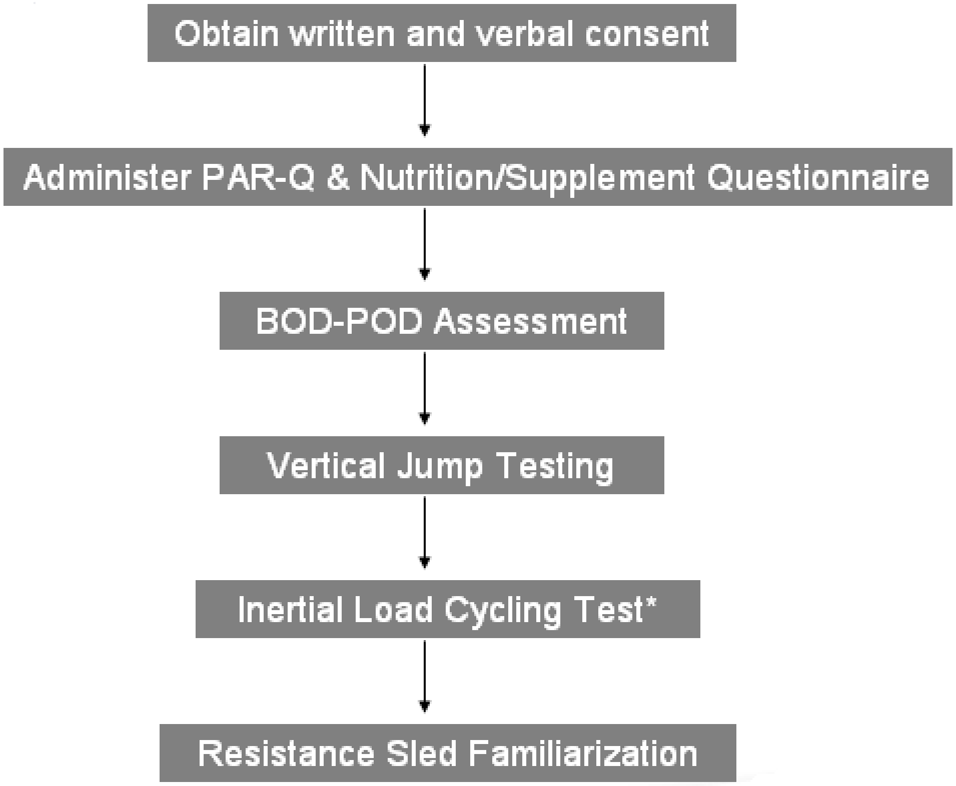
A "Vertec" measurement apparatus was also used for the vertical jump assessment (Senoh Corp., Matsuhidai, Matsudo-shi, Chiba, Japan). Standing reach was subtracted from the highest of three vertical jumps to determine vertical jump height. No approach steps were permitted, but a countermovement jump was used prior to takeoff (Fry et al., 2003). A 3-minute recovery was provided between jumps (Potteiger et al., 1999). Like the inertial load cycling test, the vertical jump test provided information on participants' muscle fiber composition. Previous research has indicated a strong correlation between vertical jump measures and muscle fiber type (r = 0.79; Fry et al., 2003).

Protocol

University IRB approval (Appendix B) was obtained before proceeding with this study. This study followed a 2 x 2 x 4 mixed factorial ANOVA repeated measures design. The study required eight testing sessions with 48 hours between each session (American Council on Exercise, 2003; Baechle & Earle, 2008).

Sessions 1-4

The first four sessions of testing served as a preliminary screening and familiarization (see Figure 1). The first session lasted approximately 1 hour and began by obtaining informed written consent from the participants, and having them fill out the PAR-Q and the drug and supplement questionnaire. Additionally, the first session



*Cycling Test Requires 2 Familiarization Sessions

Figure 1. Sessions 1-4: Preliminary Testing and Screening

involved testing for body composition using the Bod Pod (COSMED, Rome, Italy).

Later on in the first session, the participants took part in the first of two surrogate methods of testing for type II muscle fibers. The first was a vertical jump measurement, which has been found to have a strong correlation with muscle biopsy testing (*r* = 0.79; Fry et al., 2003). The second indirect measure of type II muscle fibers, was the Inertial Load Cycling test, which is also highly correlated with lean thigh volume (*r* = 0.86; Hautier, et al., 1996; Martin, et al., 1997). The Inertial Load Cycling test involved two familiarization sessions and 1 data collection session. Inertial load testing scores from the final session were averaged for the statistical analysis. Both the vertical jump and inertial load tests are noninvasive measures of lean mass and muscle fiber type, which are important factors in speed development. Although participants who obtained low scores on these tests were not excluded from the study, the results of these tests were intended to provide greater insight in the final analysis as to whether or not lean mass and muscle fiber type played a role in responses to a PAP warm-up protocol.

A final aspect of the first four sessions of preliminary testing involved having participants become familiar with the sled resistance training device. The participants had the opportunity to perform 20 yd sprints using 10%, 20%, and 30% of their respective body weight as resistance. A rationale for the use of these specific resistances is provided later in the methods section.

Sessions 5-8

The following 4 days of testing were randomized and consisted of one control trial and three experimental trials. There were 24 permutations, without repetition, of the four loads (0%, 10%, 20%, and 30%), and each participant was randomly assigned to a different order.

The control trial involved having the participants engage in a standardized warm-up, consisting of a 4-minute session of pedaling a stationary bike at 70 rpm, using a self-selected resistance (Gilbert & Lees, 2005; Linder, et al., 2010; Racinais, Hue, & Blonc, 2004). The bike warm-up was of moderate intensity, between 50-70% of each participant's maximal heart rate, and was monitored using a Polar E600 heart rate monitor (Polar Electro Inc., Lake Success, New York). This warm-up was followed by a 4-minute active rest period (Bevan, et al., 2010; Kilduff, et al., 2007; Linder, et al., 2010). The active rest periods involved having the participants walk slowly around the track and were used to eliminate the possible effects of fatigue (De-Bryun-Prevost, 1980;

Hakkinen, & Komi, 1986; Linder, et al., 2010; Nelson, Cornwell, & Heise, 1996). During the active rest periods, the Borg Rating of Perceived Exertion (RPE) was used to determine the intensity level. The goal was for participants to be at a rating of 11 or below (≤ light intensity; Borg, 1998) during the active rest period. Participants then performed the pretest (a 40 yd sprint). It is important to note that spikeless running shoes were worn by the participants as opposed to track and field spikes, during testing. The 40 yd sprint pretest was then followed by another 4 -minute active rest. After this second active rest, participants were required to sprint 20 yds without resistance (0% body weight). Again, the sprint warm-up was followed by a 4 -minute active rest period. After the third active rest, the participants were tested in a final 40 yd sprint (see Figure 2).

The three experimental trials examined the influence of different levels of 20 yd resistance sled sprinting on 40 yd sprint time. The protocol for the three experimental trials appears in Figure 3, and is loosely based on the Matthews, et al. (2010) study. Each experimental trial began with the same standardized bike warm-up used in the control trial. A 4-minute active rest period followed the standard warm-up. The active rest consisted of a slow walk around the track (De-Bryun-Prevost, 1980; Hakkinen, & Komi, 1986; Linder, et al., 2010; Nelson, et al., 1996). Although the optimal rest period may be highly dependent on individual needs, the rest period between exercises chosen for this study appears to be a favorable balance between fatigue and potentiation, and is supported in similar studies (Chatzopoulos, et al., 2007; Comyns, et al., 2006; Gullich & Schmidtbleicher, 1996; McBride, et al., 2005; McCann & Flanagan, 2010; Mitchell & Sale, 2011).

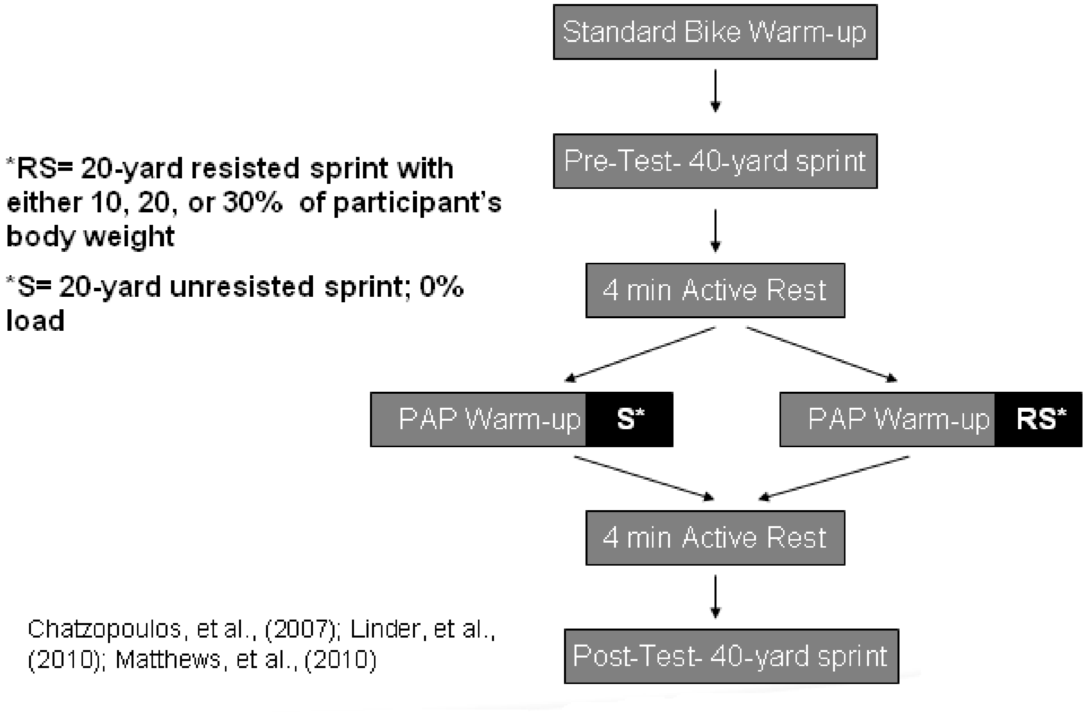
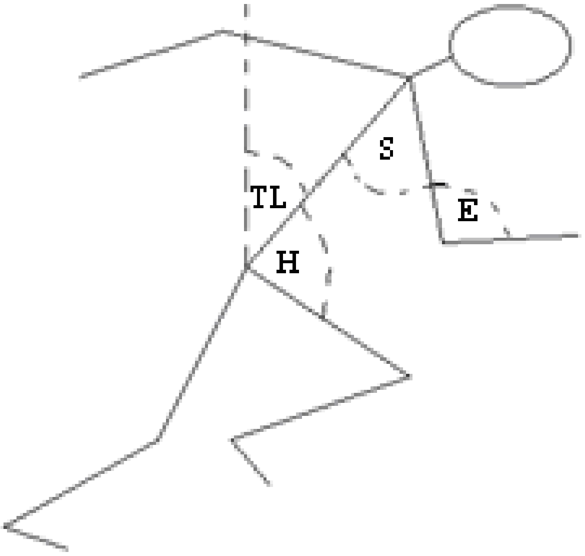


Figure 2. Sessions 5-8: Protocol for Four Warm-up Loads

The experimental trials were conducted in a manner similar to the control trial. The exception was that the 20 yd sprint portion of the warm-up involved pulling a sled. The sled and harness weighed 13.2 kg (6 lbs), and additional weights were added to the sled so that 10, 20, or 30% of each participant's respective body weight served as the sled resistance. The order of sled resistance loads (0, 10, 20, and 30%) were randomized and the 24 permutations of order meant that each participant had a unique sequence of experimental trials in an attempt to lessen any order effect.

Each 20 yd sprint was filmed using a Sony HandyCam to analyze kinematic effects of the different loads (Sony Electronics, San Diego, CA). The purpose of the analysis was to provide information on how each sled load influenced the sprint



(S = Shoulder; E = Elbow; TL = Trunk Lean; H = Hip)

Figure 3. Joint Angle Conventions

technique of the participants. The analysis was conducted from the best sagittal view of each participant, at 10 yds ± 1 stride. Body angles for trunk lean, hip flexion, shoulder flexion/extension, and elbow flexion/extension, were determined using Dartfish Video Analysis Software (Dartfish Inc. Fribourg, Switzerland). Landmarks used for kinematic analysis were the acromion (shoulder), lateral epicondyle of the ulna (elbow), midpoint between the styloid processes of the radius and ulna (wrist), anterior superior iliac spine, greater trochanter of the femur, lateral condyle of the tibia (knee) (Lockie, et al., 2003). The measured joint angles are shown in Figure 3. Hip, shoulder, and elbow angles were measured at maximum extension and flexion, and trunk lean (forward lean) was determined at touchdown of the first stride nearest to 10 yds.

Although the results of previous studies have indicated that a sled resistance greater than 10-15% body weight negatively affects sprinting kinematics, the research on PAP states that the exercises only need to be biomechanically similar, not identical (Alcaraz et al., 2008; Docherty et al., 2004; Lockie, Murphy, & Spinks, 2003). Part of the reasoning for using different sled resistance loads was to determine an optimal load for a PAP effect (Gourgoulis et al., 2003). An outline of the protocol for Sessions 5-8 can be found in Figure 2.

Statistical Analysis

Statistical analyses were conducted using Statistical Package for Social Science software version 20.0 (SPSS, Inc., Chicago, IL, USA). Descriptive statistics were calculated to characterize body composition, and muscle fiber type of the two subject populations. All data were subjected to standard data screening procedures for missing values, outliers, and testing for normality, both overall and within each group. Given the fairly small sample size, standard imputation, and accommodation were used, and small departures from normality were tolerated. All multiple trial measures (e.g., vertical jump) were assessed for precision, stability, and repeatability. The surrogate measures for fiber type were correlated using Pearson product-moment correlation. The standard for practical significance was set at 1.65%. The primary analysis was a mixed repeated measures design and was conducted using a 2 x 2 x 4 (gender, time, load) mixed Factorial ANOVA with repeated measures. Alpha was set at a value of 0.05 for this study.

CHAPTER 4

RESULTS AND DISCUSSION

This study investigated the effects of PAP warm-ups using sled sprinting, at different loads, on subsequent sprint performance. This chapter reports the results and includes a discussion.

The primary aim of this study was to examine the influence of a PAP warm-up protocol on subsequent sprint performance in well-trained, anaerobically fit individuals. The PAP portion of the warm-up was a 20 yd sprint with either 0, 10, 20, or 30% of their body weight as a resistance. Specifically, this study was aimed at determining the effects of a warm-up which culminated with a 20 yd sled resistance sprint at different loads on subsequent unresisted 40 yd sprint performance. It was hypothesized that the PAP warm-up protocols would have a statistically, and practically significant impact on subsequent sprinting performance.

It was also hypothesized that men would have faster 40 yd sprint times than women in this study, and that there would be no interaction effect between genders and sled load. Finally, it was hypothesized that the 10% body weight sled load would result in the greatest improvement in sprint performance when compared to the other sled loads.

Results

Descriptive Statistics

The participants in this study were well-trained, anaerobically fit men and women, having participated in exercise activity 4-6 days per week, for 60 minutes per session, with 75% of those activities requiring muscular power, for the previous 6 months. The average age of the participants was 23 ± 5 years, and the average body fat percentage of the participants was 19.93% (females = 24.53%; males = 15.32%). The average lean body mass of the participants was 80.08% (females = 75.47%; males = 84.68%). Twenty-two of the 24 participants fulfilled all the requirements of the study. One female and one male participant were unable to complete the study due to muscular injuries.

Initial analyses included screening for outliers using box and whisker plots and modified z-scores. One outlier was found, in which case multiple regression was used as an accommodation procedure. There were also missing values due to equipment malfunctions with the timing system, and in such cases, multiple imputation regression was used to determine approximate data for the missing values. The results indicated that no assumptions were violated for the data in the study. Initial analyses for the data collected in this study also indicated that all of the measures were reliable, with a Cronbach's α above .9 (see Table 2).

Inferential Statistics

The 2 x 2 x 4 factorial ANOVA revealed a significant difference between genders in 40 yd sprint times ($p < .001$; females = 6.04 ± .092 seconds; males = 5.30 ± .088 seconds). The results also indicated that there was a statistically significant main effect difference in pre-and post-40 yd dash times ($p < .001$; pretest mean = 5.720 ± .321

Table 2

Alpha Coefficients for Vertical Jump, Inertial Load, and 40 yd Times

	Reliability	**Stability**	
Test	Alpha	F	Sig.
Vertical Jump	.992	40.73	.000
Inertial Load	.995	5.22	.003
40 yd baseline times	.983	.33	.807

seconds; posttest mean = 5.615 ± .293 seconds). As indicated in Table 4, the participants' 40 yd dash times improved approximately 2.14% on average after the 0% load, 1.21% on average after the 10% load, 2.11% on average after the 20% load, and 2.24% on average after the 30% load. However, the four resistance levels for the PAP warm-ups (0, 10, 20, 30%), were not statistically different (see Table 3). Also, none of the interaction effects were statistically different.

Although 40 yd sprint times did not differ across the four resistance loads, running kinematics were checked as possible confounding factors. Analyses of sprint kinematics demonstrated a statistically significant difference in forward lean after comparing the 0% and 10% loads to the 20% and 30% loads ($p < .01$). When the 20% and 30% comparison was made, there was no significant difference found ($p = .695$; see Table 5). For hip flexion there was a statistically significant difference when 30% was compared to 0% and 10%, as well as when comparing the 20% load to the 0% load ($p = .001$; $p = .023$; $p = .034$; see Table 5). For shoulder flexion, a significant difference was found when comparing the 30% and 20% loads to 0% ($p < .017$; $p < .027$; see Table 5).

Table 3

2 x 2 x 4 Mixed Repeated Measures Analysis of Variance for PAP Warm-up Effects

Between Subjects	Sum of Squares	df	Mean Square	F	Sig	Power	Partial Eta Squared
Gender	25.54	1	25.54	34.41	.000	1.00	.621
Error	15.6	21	.742				
Within Subjects							
Time	.508	1	.508	29.73	.000	.999	.586
Time * Gender	.005	1	.005	.27	.610	.078	.013
Error (Time)	.359	21	.017				
Load	.087	3	.029	1.12	.347	.288	.051
Load * Gender	.022	3	.007	.28	.835	.102	.013
Error (Load)	1.625	63	.026				
Time * Load	.022	3	.007	.93	.431	.244	.042
Time* Load*Gender	.017	3	.006	.70	.556	.190	.032
Error (Time* Load)	.502	63	.008				

Table 4

Descriptive Statistics for Time Averages; % Improvement; and Time Differences

Sled load	**Pre Warm-up (sec)**	**Post Warm-up (sec)**	**% improvement**	**Time difference (sec)**
0%	5.70[a] ± .541	5.58[b] ± .502	2.14	0.12
10%	5.72 ± .507	5.65 ± .527	1.21	0.07
20%	5.70 ± .464	5.57 ± .480	2.11	0.12
30%	5.71 ± .497	5.58 ± .465	2.24	0.13

[a] Average 40 yd times in seconds prior to PAP warm-up
[b] Average 40 yd times in seconds after PAP warm-up

Table 5

Kinematic Variables for Sled Towing

Sled Load	**0%**	**10%**	**20%**	**30%**
Forward Lean	15.69	20.99	26.66[b]	28.83[b]
Hip Flexion	106.43	103.03	98.46[a]	94.73[b]
Elbow Flexion	45.52	46.5	46.73	46.32
Elbow Extension	122.03	117.45	117.18	117.40
Shoulder Flexion	38.88	44.22	48.69[a]	49.28[a]
Shoulder Extension	68.65	65.32	65.12	62.52

[a] Significantly (*p* <.05) different from the 0% load; [b] Significantly (*p* <.05) different from the 0% and 10% load; All values in degrees.

Discussion

The primary aim of this study was to examine the influence of a PAP warm-up protocol on subsequent sprint performance in well-trained, anaerobically fit individuals. Twenty yd sprints performed while pulling a resistance sled, following a 4-minute traditional warm-up, were used to create a PAP effect. Three sled loads were used, including one 20 yd sprint without resistance, constituting four different warm-up protocols. The 2 x 2 x 4 ANOVA indicated a significant difference in pre-to post-40 yd sprint times regardless of gender or sled load. The finding that the PAP warm-up benefitted both genders is consistent with previous research (Ebben, Jenson, & Blackard, 2000; Jenson, & Ebben, 2003; Xenofondos, et al., 2010). There was also a statistically significant difference between genders as hypothesized. The significant difference in pre-to post-40 yd dash times also supports the notion that resistance sprinting warm-ups can result in acute improvements in sprint times (Matthews et al., 2010). However, there were no significant differences found between warm-up protocols. Therefore, it remains somewhat unclear which load is optimal for improving 40 yd dash performance.

From a practical standpoint, it was hypothesized that the PAP warm-ups would have a practically significant impact on subsequent sprint performance (1.65% improvement). On average the results of the 10% load were less preferable than those of 0, 20, and 30%. The percent of improvement in 40 yd sprint times for the 10% load was just above a 1% improvement, whereas for the 0, 20, and 30% loads, the improvements were greater than 2%. In comparison with other studies, the percent improvements are similar, and in some cases greater. Chatzopoulos, et al. (2007) found a 1.7% improvement in 30 m times as a result of a PAP warm-up (pretest mean: 4.51 seconds; posttest mean: 4.43). Linder, et al. (2010) saw a 1.11% improvement in 100 m sprint times after the PAP warm-up they used (pretest mean: 17.14 seconds; posttest mean: 16.948 seconds). Matthews, Matthews, and Snook, (2004) found 3.3% improvements in 20 m times (pretest mean: 2.963 seconds; posttest mean: 2.865 seconds). The resistance sprint PAP warm-up study conducted by Matthews et al. (2010) resulted in a 2.6% improvement in 25 m sprint times (pretest mean: 3.95 seconds; posttest mean: 3.859 seconds).

The finding that the 10% load brought less favorable improvements than the other loads is somewhat interesting; especially when considering that previous literature has recommended that a 10-15% load is optimal when training with a resistance sled (Lockie, et al., 2003). This assertion is based on the effects of the resistance on an individuals' sprint kinematics, and provided the basis for the hypothesis that the 10% load would be optimal for improving sprint performance. However, 10% of body weight would not be 75% of maximal voluntary contraction. Although the 30% of body weight load was difficult for several participants, even that condition may not have been 75% of maximal voluntary contraction.

The video analysis of the sprints was in agreement with the idea that heavier loads disrupt sprint technique more so than with lighter loads (Lockie, Murphy, & Spinks, 2003). The effects were particularly evident when addressing forward lean, hip flexion, and shoulder flexion. However, a limitation of the video analysis was that the different areas of the participants' bodies used to aid in determining body position angles were not marked. Although the reliability for all of the measures in the study was high (Cronbach's α between .7 and .9), accuracy may have been improved had those areas been marked. At any rate, although the 20 and 30% loads had statistically more forward lean than unloaded sprinting, the 40 yd times were not statistically different. Given that the video analysis was conducted at approximately 10 yds, an additional analysis was run on 10 yd times, rather than 40 yd times. A Helmert post hoc analysis indicated that at 10 yds, the 10% load warm-up produced statistically slower times than the 20 and 30% loads (p = .047). It is a possibility that pulling heavier loads is more intense, and can cause a greater PAP effect. Exactly why the 10% load brought the least improvement remains unclear and needs further study.

A limitation to the study which could have impacted the results is the recovery time between the warm-up and sprint tests. As was mentioned previously, the recovery time needed by each participant can be highly individual. The variability of individual participant needs makes it difficult to determine an ideal recovery time. Also, because this is the first study using a resistance sled as part of the PAP warm-up, the recovery time needed to see a significant difference between sled loads may be different from other studies. Future research should address the issue of recovery time when using a resistance sled as part of the PAP warm-up.

It appears that muscle fiber type did not play a significant role in the results of the study. The average vertical jump score for males in this study was 28.92 inches; average vertical jump scores for active, healthy, adult males, as reported by Patterson and Peterson (2004), is between 21 and 22 inches. For females in this study, the average vertical jump score was 20.79 inches; Patterson and Peterson (2004) indicated that the average vertical jump score for active, healthy adult females is approximately 14 inches. The comparisons between vertical jump scores obtained by the participants in this study and the average scores for active, healthy adults suggest that the participants in this study had a higher amount of type II muscle fiber than the norm. The participants' inertial load scores for max power (watts) were lower than the norm for males and females of similar conditioning background (Hautier, et al., 1999; Martin, Dietrich, & Coyle, 2000). However, the average optimal velocity (rpm) produced by the participants in this study was higher than participants in previous research who had predominant type II muscle fibers (Hautier, et al., 1999).

It is possible that there were no significant differences between the different warm-ups because they were so similar in nature that no statistically significant effects could be found; or that the sled did not create a PAP effect. Future research might include another intervention such as a passive warm-up, or a true control condition. A common question in research on warm-ups is whether performance improvements are primarily due to increased body temperature, or a combination of PAP, body temperature increase, and other factors (Bishop, 2003). The inclusion of a passive warm-up or a true control could help improve understanding in this area of study. It is also possible that the pre-warm-up 40 yd sprint could have had a PAP effect for all four conditions.

Another question that may be asked is whether the resistance sprints were long enough in duration to produce a desirable effect. Matthews et al. (2010) used a 10 second resisted sprint and found a 2.6% decrease in sprint times. In the current study, participants pulled a sled 20 yds, approximately half the time of the resisted sprints in the Matthews et al. study, and the greatest improvements in sprint times were slightly above 2%. The Matthews et al. study also had the participants in the comparison group rest between pre-and postsprint tests, whereas in the current study, participants ran a 20 yd sprint with 0% of their body weight as resistance. The inclusion of a sprint with 0% body weight may be more typical of a warm-up for sprint testing. Researchers may wish to consider the duration of the sled sprints, and as mentioned previously, include a passive warm-up, or a rest period without any sprints between pre-and postsprint tests, for future studies. The use of a squat warm-up, as has been used in other studies to enhance sprint performance, should also be considered as an additional intervention.

Another limiting factor in the study was that there were not enough participants in the study as indicated by the low statistical power (.24). Although the a priori power analysis estimated that 24 participants would be needed for the study, due to the uniqueness of this study and the methods used it was not possible to know the exact number of participants needed beforehand. The Matthews et al. (2010) study, which the a priori power analysis was based on, had differences with respect to participants (only male; less total participants), and the type of PAP warm-up used. Based on the study by Matthews et al. (2010), an effect size of 1.2 was estimated. The effect size in this study for the time by load interaction effect was only .65. Almost twice as many participants as the study by Matthews et al. (2010) were needed for this study to detect an effect of .65. Whether or not statistical significance could be reached with a greater number of participants is unclear.

Because this is one of the first studies to examine the effects of PAP on sprint performance using a modality (sled sprint) that is different from the more conventional warm-up devices (e.g., squat) used in other PAP studies, there are many questions that remain unanswered. Overall, this study does indicate a potential for heavier sled resistances to bring about acute decreases in 40 yd sprint times when used in a warm-up. However, the benefit may not be greater than unresisted sprinting. Fitness trainers and coaches should use some caution when considering whether or not to include heavier sled loads as part of a training program. Further study is needed to determine whether or not chronic adaptations to training with heavier sled loads can have negative effects on sprint kinematics, and sprint performance (Lockie et al., 2003). At any rate, a replication of this study is warranted, which includes but is not limited to: a greater number of participants, an additional intervention such as a passive warm-up, and body markings to aid in kinematic analyses.

Limitations of the Study

The following limitations were recognized for this study:

1. The population used in this study was a nonprobability sample. Participants were recruited based on availability and convenience, but also because they possessed characteristics that were important for this study. The sample used for the study was well-trained, anaerobically fit, college students located in the Southwestern region of the United States.
2. The participants may not be representative of the total population of college students with this particular conditioning background.
3. The methods used in this study for determining type II muscle fibers are indirect.
4. The recovery period between the warm-up and subsequent power activity is 4 minutes, and may not be as effective as others for the warm-up used in this study.
5. The target areas of the participants' bodies used to aid in determining body position angles for kinematic analysis were not marked.
6. The sample size was not adequate for acceptable power.

Strengths of the Study

The following strengths were recognized for this study:

1. The use of a resistance sled in a PAP warm-up study. This is only the second study examining the effects of resistance sprinting on subsequent sprint performance; and, the first to gauge the resistances used.
2. The study used several preliminary tests (inertial load, vertical jump, and bod pod) to determine and categorize the participants in terms of lean mass and muscle fiber composition, and correlate the tests with sprint performance.
3. All of the data collected in the study were found to be highly reliable.
4. Both men and women participated in the study. The majority of the studies on PAP use a single gender.

CHAPTER 5

SUMMARY, FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The primary aim of this study was to examine the influence of a PAP warm-up protocol on subsequent sprint performance in well-trained, anaerobically fit individuals. Twenty yd sprints pulling a resistance sled, following a 4 -minute traditional warm-up, were used to stimulate a PAP effect. Three sled loads were used, including one 20 yd sprint without resistance, constituting four different warm-up protocols. The participants in this study were 24 well-trained, anaerobically fit men and women, ages 18-28, from a University in the Southwestern United States. The study required 8 total visits of the participants. The protocol for the first four sessions included: completion of a modified PAR-Q, and nutrition and supplement questionnaire; an assessment of body composition (BOD POD); a vertical jump assessment; a cycling power (inertial load) test, which included two familiarization sessions and one testing session; and finally, participants completed a familiarization session sprinting with a resistance sled at different resistances.

During the last four sessions of the study, the participants were pretested in the 40 yd dash on four separate days prior to conducting a PAP warm-up that included a resistance sprint of either 0, 10, 20, or 30% of their respective body weight. There were 24 permutations, without repetition, of the four loads (0%, 10%, 20%, and 30%), and each participant was randomly assigned to a different order. Each resistance sprint was video recorded for kinematic analysis. Forward lean, hip flexion, and shoulder and elbow flexion and extension were all analyzed. After conducting the PAP warm-up for each day, a post-40 yd dash time was recorded.

Findings

Results for this study were generated using Statistical Package for Social Science software version 20.0 (SPSS, Inc., Chicago, IL, USA). A 2 x 2 x 4 factorial ANOVA revealed a statistically significant difference between genders in 40 yd dash times ($p < .001$), with men having faster times. A significant main effect difference was found in pre-to post-40 yd dash measures ($p < .001$) for each intervention regardless of gender. The results also indicated that for the four resistance sled warm-ups tested (0, 10, 20, 30%), there were no statistically significant differences in the post-warm-up 40 yd dash times between loads, and the sled load by time interaction was not statistically significant ($p = .431$). The participants' 40 yd dash times improved approximately 2.14% on average after the 0% load, 1.20 % on average after the 10% load, 2.11% on average after the 20% load, and 2.20% on average after the 30% load.

Analyses of sprint kinematics demonstrated a statistically significant difference in forward lean after comparing the 0 and 10% loads to the 20 and 30% loads ($p < .01$). For hip flexion there was a statistically significant difference when 30% was compared to 0 and 10%, as well as when comparing the 20% load to the 0% load ($p =.001$; $p =.023$; $p =.034$). For shoulder flexion, a significant difference was found when comparing the 30 and 20% loads to 0% ($p < .017$; $p < .027$).

Conclusions

Postactivation potentiation warm-ups need to be given more attention as a strategy for enhancing power, particularly in regard to sprint performance. This study is unique in that it is the first to address the influence of a PAP warm-up using a resistance sled, on sprint performance. More research is needed in order to determine if the warm-up protocols used in this study are preferable to other PAP and non-PAP warm-up protocols. Although no statistical differences were found between the warm-ups in this study, the results do indicate a potential for heavier sled resistances to bring about acute improvements in 40 yd sprint performance when used in a warm-up. Even after statistically significant disruptions in sprint mechanics, this appears to be the case. In fact, the improvements in sprint performance with the heavier loads appear to be more desirable than those of the lighter 10% load. At any rate, a replication of this study is needed, which includes, but is not limited to: a greater number of participants, and additional interventions such as a passive warm-up, and also a PAP warm-up that uses squats.

Recommendations

Based on the results of this study, the following recommendations for future research are made:

1. Replicate the study with a greater number of participants.
2. Replicate the study with an additional intervention (e.g., a passive warm-up, a squat PAP warm-up, or a rest period in place of a sled pull between pre-and post-40 yd time tests).

3. Use body markings for the sprint kinematics analysis. Analyze the sprint mechanics from as sagittal view of the first and second stride of the sled pull as opposed to the 10 yd mark.
4. Study a different recovery time to determine if there is an optimal balance between recovery from fatigue and PAP effect.
5. Conduct the study with participants of different conditioning backgrounds (e.g., elite track sprinters, or football players) to further understand the effects of the warm-up protocols with specific populations.
6. Test the chronic effects of training with the different sled loads on 40 yd dash performance.
7. Select a different recovery time for the warm-up to test its effects.
8. Test the effects of pulling sled loads at different durations, distances, and intensities (e.g., heavier sled loads).
9. Test other ways to enhance the intensity of the PAP warm-up such as weighted vests.

Recommendations for Coaches and Athletes

Although more research is needed, the findings of this study suggest that athletes may benefit from using heavier sled loads as part of a PAP warm-up for enhancing sprint performance. Lighter sled loads may be less desirable and could potentially bring less favorable improvements for athletes if used prior to testing or competition. Although using heavier sled loads to improve acute power performance may be appropriate, using heavier loads as part of a regular training program could potentially be harmful to an athlete’s sprint technique and needs further study;

therefore, it is not recommended at this time. It is also not entirely clear whether using a resistance sled is more advantageous than using unresisted sprints as part of a PAP warm-up strategy for improving sprint performance.

This study has not investigated the effects of a heavy weight back squat as a means for enhancing sprint performance, however, sled pulls are biomechanically more similar to sprinting than squats, specifically in relation to the line of application of force. Also, sled towing may be a more feasible method of warming up than squats because of the minimal equipment needed.

APPENDIX A

PAR-Q, NUTRITION, AND SUPPLEMENT QUESTIONNAIRE

PAR-Q, Nutrition, & Supplement Questionnaire

Age_____ (you must be 18-28 years old for this study) Height______
Weight_____ Ethnicity_________ Gender____

Yes	No		
_____	_____	1.	Has a doctor ever said you have a heart condition and recommended a medically supervised physical activity program?
_____	_____	2.	Do you have chest pains brought on by physical activity?
_____	_____	3.	Have you developed chest pains within the last month?
_____	_____	4.	Do you tend to lose consciousness or fall over as a result of dizziness?
_____	_____	5.	Do you have a bone or joint problem that could be aggravated by the proposed physical activity?
_____	_____	6.	Is a doctor currently recommending medication for blood pressure or heart condition?
_____	_____	7.	Have you been diagnosed with high blood pressure?
_____	_____	8.	Do you have Diabetes?
_____	_____	9.	Are you aware, through your own experience or a doctor's advice of any other physical reason against your exercising without medical supervision?
_____	_____	10.	Are planning on making any significant changes to your diet in the next 2 weeks?
_____	_____	11.	Do you take legal supplements? (if no, skip question #12)
_____	_____	12.	If you answered yes to question 11, will you remain on the same legal supplementation regime for the duration of this study?
_____	_____	13.	Have you ever used illegal Ergogenic aids or nutrition supplements?

Yes	No		
_____	_____	14.	Have you experienced any injuries in the past 6 months which have limited you ability to exercise?
_____	_____	15.	Have you engaged in physical activity 4-6 days per week, for 60 minutes per exercise session, with 75% of those activities requiring muscular power, for the past 6 months? If yes, in the space below, please include a brief description of the exercise activities you have been involved in for the previous 6 months:

I ______________ certify that the above information is correct and true to the best of my knowledge.

Dated this the ______day of _______________, 20_______

________________________________ ________________________________

Print Name Signature

***If you have questions or concerns please check with Chad Smith (801)695-5271, the Principal Investigator in this study.**

APPENDIX B

INFORMED CONSENT

Consent Document

BACKGROUND

You are being asked to take part in a research study. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether you want to volunteer to take part in this study.

The purpose of this study is to examine the influence of a postactivation potentiation (PAP) warm-up protocol on subsequent sprint performance in well-trained, anaerobically fit individuals. PAP is an enhanced neuromuscular state observed immediately after a high intensity exercise. If biomechanically similar, power type activities are performed while the muscles are in this enhanced state, then performance may be enhanced (Robbins 2005).

Specifically, this study will aim to determine the effects of sled resistance sprinting at different loads on subsequent unloaded sprints. A resistance sled is attached to the athlete by a 3.6 meter cord and waist harness (Power Systems Inc., Knoxville, TN). The sled travels on two parallel metal tubes that are approximately 400 mm long, and 30 mm in diameter. Sled towing is a common practice used in resisted sprint training (Lockie et al., 2003). Its design allows for weights to be easily secured to or removed in order to adjust the degree of resistance, and consists of a metal sled, nylon rope, and harness.

This study is being completed by Chad Smith. He is a graduate student specializing in Sport Pedagogy in the Department of Exercise and Sport Science at the University of Utah.

STUDY PROCEDURE

It will take you approximately 10 days to complete this study. It will involve 1 preliminary testing session, which will be followed by 4 randomized trials. Each testing day will be separated by 48 hours. During the first session, you will be asked to complete questionnaires on physical activity readiness, nutrition, and supplement intake. This will be followed by an assessment of your body fat and lean muscle mass using the BOD POD. The BOD POD is a computerized, egg shaped machine which you sit in for 2-min in a bathing suit breathing normally. You will then be tested on vertical jump. The vertical jump will involve leaping vertically as high as possible using both arms and legs to assist in projecting your body upwards. This is followed by the Inertial Load Cycling test. The test involves participating in 4 bouts of maximal acceleration cycling. You will pedal a stationary bicycle as fast as possible for 3-4 seconds. This is repeated for a total of 4 bouts with a 2 -minute rest period provided between each bout. Following these tests the first session will conclude with a sled resistance familiarization period. This involves pulling a resistance sled for 20 yds, at loads of 10, 20, and 30% of your body weight.

The 4 randomized trials will include the following steps in order: a) standardized cycling warm-up; b) a 40 yd sprint pre-test; c) 4 minutes of active rest; d) a second warm-up which, depending on the day, consists of a 20 yd sprint of either 0, 10, 20, or 30% of your body weight as resistance; e) another 4 minutes of active rest; f) a final 40 yd sprint post-test.

RISKS

The risks of this study are minimal. You may feel a bit uncomfortable if you are self conscious about being tested in the associated areas of health and fitness. For example, you may experience some emotional discomfort if you are uncomfortable with being seen in a swimsuit or tight fitting clothing during the BOD POD test. If you feel upset from this experience, you can tell the researcher, and he will assist you and can also tell you about other available resources to help.

Other foreseeable risks or discomforts to the participants in this study include all those associated with exercise: fatigue, possible risk of musculoskeletal injury, and cardiac events may also be possible, but the likelihood of such an incident is low.

BENEFITS

No direct benefits can be promised as a result of taking part in this study. However, you may see an improvement in your individual sprint performance as a result of conducting the warm-up routine in this study. It is also hoped that the information obtained from this study may help develop a greater understanding of warm-up protocols for enhancing performance in power activities such as sprinting.

CONFIDENTIALITY

Your data will be kept confidential. Data and records will be stored in a locked office or on a password protected computer located in the researcher's work space. Only the researcher and members of his study team will have access to this information.

PERSON TO CONTACT

If you have questions, complaints or concerns about this study, you can contact Chad Smith at 801-695-5271 or at chad.e.smith@utah.edu If you feel you have been harmed as a result of participation, please call Chad Smith at 801-695-5271 (available 24-hours a day).

INSTITUTIONAL REVIEW BOARD

Contact the Institutional Review Board (IRB) if you have questions regarding your rights as a research participant. Also, contact the IRB if you have questions, complaints or concerns which you do not feel you can discuss with the investigator. The University of Utah IRB may be reached by phone at (801) 581-3655 or by e-mail at irb@hsc.utah.edu.

VOLUNTARY PARTICIPATION

It is up to you to decide whether to take part in this study. Refusal to participate or the decision to withdraw from this research will involve no penalty or loss of benefits to which you are otherwise entitled. This will not affect your relationship with the investigator.

COSTS AND COMPENSATION TO PARTICIPANTS

There are no costs other than the time spent to fill out the questionnaires. You will not be compensated for participation.

CONSENT

By signing this consent form, I confirm I have read the information in this consent form and have had the opportunity to ask questions. I will be given a signed copy of this consent form. I voluntarily agree to take part in this study.

____

Printed Name of Participant

____________________________________ ______________________

Signature of Participant Date

____

Printed Name of Person Obtaining Consent

____________________________________ ______________________

Signature of Person Obtaining Consent Date

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