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The acute effects of multiple resisted sled-pull loads on subsequent sprint-running performances

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THE ACUTE EFFECTS OF MULTIPLE RESISTED SLED-PULL LOADS ON SUBSEQUENT SPRINT-RUNNING PERFORMANCES

An Abstract of a Thesis
Submitted
in Partial Fulfillment
of the Requirements for the Degree
Master of Arts

Carl Stephen Crouse
University of Northern Iowa
December, 2015

ABSTRACT

Sled-pulling is a commonly implemented form of training for various sports. However, few studies have used sled-pulling as a means of acutely enhancing sprint-running performances. The purpose of this study was to investigate how various sled-pulling resistance loads (95% and 110% of body mass) effect subsequent, unloaded, sprint-running performances, possibly with aid from the effect known as Post-Activation Potentiation (PAP). PAP is a physiological phenomenon which increases the rate of force development of skeletal muscle which may result in the enhancement of power (speed-strength) dominant activities such as sprint-running and jumping.

Participants were a mix of males (n = 11; age 23.3 ± 1.8 years) and females (n = 4; age = 23.0 ± 3.2 years) who were either recreationally trained, division I collegiate athletes, or strength and conditioning coaches, all of whom regularly employed sprint-running as part of their normal training program. The participants of this study underwent 2 experimental sled-pulling conditions (95% and 110% of body mass, respectively) as well as a third, unresisted, testing day which acted as the control. Each session was performed on a seperate day. On each experimental day, the participants ran timed, unresisted, 30-meter sprint-runs both before (pre-testing) and after (post-testing) the implementation of the sled-pulling condition. The uinresisted (control) condition consisted of two unresisted 30-meter sprint runs. The first of these sprints acted as the pre-test and the second sprint acted as the post-test. All unresisted sprints were electronically timed at the 10-, 20-, and 30-meter split marks as well as through the duration of the sprint.

A repeated-measures, pre-experimental design was used and the order in which the testing sessions were performed was randomized. Descriptive statistics (mean ± SD) were calculated for all performance variables. A 2X3 factorial MANOVA (time x pulling condition) was used to determine the effect of sled-pulling on sprint performance. Paired samples t-tests with Bonferronni adjustment were used as post hoc analysis when appropriate. The level of significance was set at $p<0.05$ for all inferential statistics.

The results of the 2x3 repeated measures MANOVA indicated that there were no significant interactions ($F(6,9)=0.31$, $p=0.92$) therefore main effects were analyzed. There was no significant load effect ($F(6,9)=1.15$, $p=0.41$) indicating that the loading strategy had no effect on sprint performance. There was a significant time effect ($F(3,12)=5.7$, $p=0.012$). The post hoc analysis indicated that the post-testing sprint trial (regardless of loading strategy) was significantly slower than the pre-testing trial for first ($F(1)=5.5$, $p=0.034$) and second splits ($F(1)=9.4$, $p=0.008$). There was no difference between the pre- and post-testing trials for third split ($F(1)=0.71$, $p=0.41$).

In conclusion, the heavy sled-pulling loads implemented in this study did not acutely enhance subsequent sprint-running performances. Furthermore, future studies implementing sled-pulling as a means of enhancing subsequent unresisted sprint-running performances can be directed at a wide variety of variables due to the limited amount of research that has been conducted in this area of sprint training.

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This Study by: Carl Crouse

Entitled: THE ACUTE EFFECTS OF MULTIPLE RESISTED SLED-PULL LOADS ON SUBSEQUENT SPRINT-RUNNING PERFORMANCES

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Degree of Master of Arts: P.E. Kinesiology

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Date	Dr. Kavita R. Dhanwada, Interim Dean, Graduate College

DEDICATION

This work is dedicated to my Mom, Carlene. Thank you for always believing in me, even when I didn’t believe in myself. You are a rock because you build on the rock. You have helped teach me where true strength comes from, not so much by telling me, but by showing me. I love you; you are an awesome Mom and friend.

ACKNOWLEDGEMENTS

I would be remissed in my duties if I did not acknowledge the one above whom there is no one else, my Lord and Savior, Jesus The Christ. He gives me life and he lets me find it through the passions that I pursue. He has brought many people into my life; people who have given me opportunities to learn and grow. Few people have positively impacted my life much as Jed Smith and Dominic (Nick) Davis. By trade, Jed and Nick are strength and conditioning coaches, but the most important thing about these men is that they are men of high integrity. These two have not just taught me how to be a better coach; they have helped teach me about what it means to be a good man. I am privileged and blessed to have mentors and friends such as these.

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CHAPTER I

INTRODUCTION

It is widely acknowledged that sprinting performances, such as sprint-running and ice-skate sprints, play an integral role in the success of many power- (speed-strength) dominant sports (Alcaraz, Paolo, Elvira, & Linthorne, 2008, Alcaraz, Paolo, & Elvira, 2009; Bennett, Sayers, & Burkett, 2009; Clark, Stearne, Walts, & Miller, 2010; Little & Williams, 2007; Lockie, Murphy, & Spinks, 2003; Matthews, Comfort, & Crebin, 2010; Maulder, Bradshaw, & Keogh, 2008; Paulson & Braun, 2011; Smith, 2012; Spinks, Murphy, Spinks, & Lockie, 2007; Young, Benton, & Guthie, 2001). This fact has recently been the focus of several research studies whose goal is to enhance various types of sprint performances through various methods such as resisted sprinting techniques (Alcaraz et al., 2008, Alcaraz et al., 2009; Bennett et al., 2009; Bosco, Rusko, & Hiroven, 1986; Clark et al., 2010; Harrison & Bourke, 2009; Kristensen, Tillaar, & Ettema, 2006; Lockie et al., 2003; Matthews et al., 2010; Maulder et al., 2008; McBride, Nimphius, & Erickson, 2005; Paulson & Braun, 2011; Smith, 2012; Spinks et al., 2007; Yetter & Moir, 2008). The techniques implemented in these studies have been wide ranging. Speed parachutes, weighted vests, lower extremity weights, sled-pulling, and other resistance-providing devices and techniques similar to sled-pulling, have all been methods used in order to try to enhance sprint-running acceleration as well as, top-end, sprint-running speed.

Of the techniques mentioned previously, sled-pulling is one of the most commonly utilized methods in which to try to enhance sprint-running performance

(Alcaraz et al., 2008; Alcaraz et al., 2009; Clark et al., 2010; Harrison & Bourke, 2009; Lockie et al., 2003; Maulder et al., 2008; Paulson & Braun, 2011; Smith, 2012, Spinks et al., 2007; Young et al., 2001). The evaluation of sled-pulling and devices and techniques which apply resistance similar to a sled-pulling condition have been studied in two different ways. One of the ways in which sled-pulling, and similar devices, have been evaluated is with regard to their immediate effect on sprint-running technique. The reason to study sled-pulling's effect on sprinting technique is to attempt to answer the question of how sled-pulling, and similar resistance methods, may change sprint-running technique and, in the process, change efficiency of the movement patterns during sprint-running.

The second way that sled-pulling, and similar devices, have been analyzed is through longitudinal use. These training studies are longer-term in nature, and have ranged from three weeks to eight weeks in duration, (Clark et al., 2010; Harrison & Bourke, 2009; Kristensen et al., 2006; Spinks et al., 2007) which is a traditional duration for a training study of this kind. The primary goal of these longitudinal studies is to evaluate the effect that sled-towing and other similar resistance methods have on the speed of sprint-runs, when used on a regular basis. Although the information presented in the existing literature has been a valuable tool in increasing the effectiveness of sprint training, it is far from complete.

Furthermore, some recommendations for the use of resisted sprinting techniques are only assumed. For example, a common recommendation found in the literature suggests that the use of a resistance which reduces an athlete's average sprint-running speed by more than 10%, over a given distance, should not be used (Alcaraz et al., 2009; Bennett et al., 2009; Lockie et al., 2003; Maulder et al., 2008; Paulson & Braun, 2011; Spinks et al., 2007). Most of this research has either suggested or shown that a resistance load equaling approximately 10% of an individual's body mass is the maximum resistance load to be used in order to keep average sprint-running speed at, or above, 90% of the average sprint-running speed. The assumption is that reductions in maximal sprint-running speed, caused by the use of external resistance, which are greater than 10%, will cause great changes in sprinting technique, thereby reducing sprinting efficiency during the subsequent unresisted sprinting condition.

However, despite this assumption, no empirical data has actually been collected which shows that unresisted sprinting technique is actually altered after the implementation of a resistance load which has caused a reduction greater than 10% in sprinting speed, over a given distance. Furthermore, it has been suggested that, if sprinting technique changes do occur, then these changes actually may benefit an athlete, particularly if the heavy loads actually help the athlete sprint faster during the unresisted condition (Alcaraz et al., 2009; Lockie et al., 2003; Maulder et al., 2008; Paulson & Braun, 2011).

Limited research has been conducted with regard to sled-pulling and the possible acute enhancements on subsequent sprint-runs (Smith, 2012). The possible acute enhancements of sprint-runs which follow a sled-pull, if they indeed occurred, would likely be caused by an effect known as post-activation potentiation. Post-activation Potentiation or "PAP" as it is commonly known, is a physiological phenomenon, which create an environment in skeletal muscle, and nervous tissue that may allow for an increase the rate of force development of skeletal muscle (Tillin & Bishop, 2009). Several studies have shown that maximally, or near maximally, stressing skeletal muscle via muscle contraction may very well result in the induction of PAP (Chiu, Fry, Schilling, Johnson, & Weiss, 2004; Hamada, Sale, Macdougall, & Tarnopolsky, 2000; Jo, Judelson, Brown, Coburn, & Dabbs, 2010; Kilduff et al., 2007; Matthews et al., 2010; McBride et al., 2005; Ruben et al., 2010; Yetter & Moir, 2008).

The increase in the rate of force development of skeletal muscle that may result from PAP may lead to the enhancement of power (speed-strength) dominant activities. Due to the common use of sled-pulling as a means of resisted sprint-training, it would seem logical that, if relatively heavy sled-pulling can enhance subsequent sprint-running performances via PAP, then it would be to the benefit of many athletes and coaches to know how this method can best be implemented. Furthermore, using sled-pulling as a means of inducing PAP for sprint-running may be preferred to other methods of PAP induction because sled-pulling may be more specific to sprinting than many other methods.

After being introduced to the aforementioned information, it becomes clear that some major gaps exist in the literature surrounding resisted sprinting methods. It is for this reason, that the research to be proposed is trying to fill in some of these gaps regarding a very commonly utilized resisted sprinting technique, the sled-pull.

Statement of the Problem

The purpose of this research is to investigate how various sled-pulling resistance loads (95% and 110% of body mass) effect subsequent, unloaded, sprint-running performances, possibly with aid from the effect known as Post-Activation Potentiation or PAP.

Research Questions

This particular study is trying to answer three primary questions. These questions are (1) is the acute use of heavy sled-pulling effective in producing faster sprint-runs? and, (2) if there is an effect, then, at what resistance load is the greatest effect achieved? and, (3) is unresisted sprint-running, itself, an effective means of causing potentiation which may enhance subsequent sprint-running performances?

Hypotheses

The researcher of the current study made three hypotheses, which are as follows… (1) Heavy sled-pulling would induce a Post-Activation potentiation (PAP) effect that will enhance the performance of subsequent sprint-running peformances. (2) Heavy sled-pulling conditions will cause greater enhancements to subsequent sprint-runs than will the condition which implements no extra external resistance. (3) Unresisted sprinting, itself, for this study, would not be an effective means of causing potentiation which may enhance subsequent sprint runs.

Significance of the Study

The study to be proposed has several reasons why it can be viewed as significant within the athletic development community. One reason may come through the acute enhancement of sprint-running speed. If shown to be significant in enhancing running speed over a distance of 30 meters, then the technique of heavy sled-pulling has the possibility of being used while warming-up before a game such as American-football, baseball, or a track event like sprint-running, all of which are largely power-dominant activities. It would seem practical to use sled-pulling in this way because sleds are widely used and could be readily available on the field or sidelines for many of these events.

Another reason why the study is important is because it will use resistance loads which are greater than those commonly recommended. The existing literature often says that resistance loads which cause a participant to run at speeds less than 90% of their average maximal speed over a given distance will significantly alter running technique (Alcaraz et al., 2009; Bennett et al., 2009; Lockie et al., 2003; Maulder et al., 2008), although it is not said outright, it can be inferred that this change in technique may cause an athlete to become slower in a subsequent unresisted condition. However, no data exists which actually proves that these inferences are indeed true. Although, as was mentioned earlier, no video analysis will be used in the study to be proposed, some simple inferences can be made based on the sprint running performances of the study. If sprint-running times which occur after the heavy sled-pulling conditions are faster than the baseline sprints, then it may very well be that heavier than recommended sled-pulls may be beneficial to sprint kinematics or they may not have had a significant carry-over effect which would act to cause a significant change in running kinematics. A finding such as this could spur further research into the area of heavy sled-pulling and its carry-over effects to subsequent sprint runs.

The third reason why the study to be proposed has importance is because it uses a commonly utilized resisted sprinting method (sled-pulling) and therefore, if effective, heavy sled-pulling could be widely used to enhance speed-strength performances through the induction of PAP.

Delimitations

The participants of this study were a mix of 15 athletes and strength and conditioning coaches who have had experience teaching and/or performing sprints which start from a three-point starting stance.

All timed sprint-runs were a distance of 30-meters, and the sprint-running times were measured at each 10 meter interval (at the 10-, 20-, and 30-meter marks of each sprint) with the use of a Brower brand electronic timing system.

Sled-pulling was used as the method by which to attempt to induce a PAP effect among the participants in the study. Two different heavy sled-pulling loads were pulled in an effort to achieve PAP and, hopefully, enhance subsequent, unresisted, sprint-runs when compared to unresisted baseline sprint-runs performed prior to each of the sled pulling conditions. Unresisted running was the third method by which PAP may be enhanced, and this unresisted session will be compared to the resisted running session outcomes. A minimum of three days of rest elapsed between each condition. This allowed for a sufficient recovery between each of the three testing sessions.

A repeated-measures, pre-experimental design was used. This means that every participant of the study underwent each of the three conditions. The order in which the participants performed each testing session was randomized and a repeated measures 2x3 Multivariate Analysis of Variance (MANOVA) was used to interpret the findings.

Limitations

There were some limitations to the study that was performed, one of which was the sled-towing loads that were implemented based on the nature of the surface that the sled was pulled on (football field turf). The weight had to be sufficient so as to stress muscle to a point at which PAP can be achieved.

Furthermore, another limitation was caused by using standard percentages based on each individual's body weight rather than basing the weight to be pulled on the strength levels of each individual. This means that, potentially, a person who is very strong relative to his or her body weight may have not achieved potentiation because the weight that they are pulling may have been too perfect. An alternate scenario may be observed in someone who is much weaker, relative to his or her body weight. Although the load that is pulled may have been sufficient to allow a physically weaker individual to achieve a PAP effect, the possible benefits from the PAP may have been overshadowed by short the term fatigue induced by the sled-pull, this is a scenario which has been suggested in an article by Ross, Leverritt, and Riek (2001).

The final limitation was that the participants of the study all had previous experience in the implementation of sprint-training and heavy resistance training. This means that someone who may try to apply the findings of this study to an individual, or population who has little or no prior sprint-training or heavy resistance training experience may have different results.

Assumptions

Based on the findings of previous, albeit limited, research surrounding sled-pulling, and similar resisted sprinting methods, and PAP (Matthews et al., 2010; Smith, 2012), it was assumed that heavy sled-pulling would cause a potentiation effect that would enhance the performance of subsequent sprint-runs. It was also assumed, due to the added resistance, that heavy sled-pulling would cause greater enhancements to subsequent sprint-runs than the condition which implemented no extra external resistance. Another assumption by the researcher was that the participants of the study would give maximum effort during the testing sessions so that PAP could be achieved if the particular experimental and control conditions implemented in the study had the potential to induce PAP. The final assumption made was that the instrumentation used for timing sprints and collecting body mass data of the participants were reliable and valid.

Definition of Terms

Acute Study: A Study in which an experimental condition (i.e. sled-pulling) and its effects on an outcome which follows the experimental condition (i.e. sprint times or sprinting-kinematic changes) occur within the same testing session (Hodgson, Docherty, & Robbins, 2005).

Longitudinal Study: A study lasting for several weeks. In the case of this review, the longitudinal studies referred to last anywhere from three to eight weeks looking for changes which occur over the several weeks of the study and not short term outcomes, such as in an acute study (Hodgson et al., 2005).

Kinematics: This is the mechanics, commonly referred to as the “form,” of a movement. Kinematics is the measured movements of body segments or joints, such as the range of motion (measured in degrees) at a joint during a movement (Hamilton, Weimar, & Luttgens, 2008, p.611). Sprint kinematics is, therefore, the measurements of body segments or joints which occur during sprinting, or more accurately a phase of the sprint.

Triple extension/extensors: Muscles which cause the extension of the hip, knee, and ankle joints, which are the basis of athletic power (Spinks et al., 2007).

Unresisted Sprint: A sprint performed without any added external resistance (Kristensen et al., 2006).

Overload: Adding some sort of external load (weight) to achieve an effect (i.e. muscle strengthening or post-activation potentiation (Foran, 2001, p.13).

Post-Activation Potentiation: The acute enhancements of muscular performance characteristics which occur after skeletal muscle has been maximally or near maximally contracted (Tillin & Bishop, 2009).

Rate of force Development: The time it takes to generate a given amount of force (Siff, 2003, p.107).

CHAPTER II

REVIEW OF RELATED LITERATURE

In an effort to fully understand the reasons for conducting the study to be proposed, it is imperative to review the related information which already exists surrounding the topic. In reviewing the related literature, we can begin to understand the potential which resisted sprinting has already been shown to have in enhancing the unresisted sprinting condition. Conversely, the following literature review will also attempt to expose some of the limitations of the recommendations, which have resulted from these studies, regarding the implementation of resisted sprinting. It is in this way, that we can gain an accurate understanding of the study of the study to be proposed.

Resisted Sprinting

Resisted sprinting is commonly used in hopes of enhancing unresisted sprint performances, and it can be implemented in a variety of ways, ranging from: (a) weighted sled-pulling, (b) resistance parachute, (c) weighted vest, (d) weighted belt, (e) lower extremity weights, etc. (Alcaraz et al., 2008; Alcaraz et al., 2009; Bennett et al., 2009; Bosco et al., 1986; Clark et al., 2010; Harrison & Bourke, 2009; Jo et al., 2010; Kristensen et al., 2006; Lockie et al., 2003; Matthews et al., 2010; Maulder et. al, 2008; Paulson & Braun, 2011; Spinks et al., 2007). The previous studies of resisted sprinting methods have attempted to evaluate how each of these methods affect critical factors of sprinting such as the effects on kinematics during the different phases of sprinting (acceleration and maximal speed phase). Based on the loading techniques and the weight of the loads used in various studies, researchers have also made recommendations about optimal resistance loads which should be implemented, as well as how these loads effect muscle strength and force output, both, over time, as well as acutely.

Choosing a Resistance Load

Regardless of which resisted sprinting method is implemented, choosing a correct resistance load is critical (Alcaraz et al., 2008; Alcaraz et al., 2009; Bennett et al., 2009; Harrison & Bourke, 2009; Hunter, Marshall, & McNair, 2004; Kristensen et al., 2006; Lockie et al., 2003; Maulder et al., 2008; Paulson & Braun, 2011; Spinks et al., 2007). During longitudinal use of resisted sprinting, optimal resistance can allow an individual to become a faster sprint-runner by increasing the rate of force development, over time, of the muscles which are primarily responsible for the extension of the hip, knee, and ankle joints, also known as the triple extensors. During longitudinally implemented resisted sprint training, an individual inherently takes a greater period of time, when compared to acute loading methods, in which to reach an optimal level of the neuromuscular functioning in order to enhance his or her ability to perform a sprint. It has been suggested that the regular use of resisted sprinting sessions, over a period of several weeks or months, seems to allow myogenic changes (changes within the exercising muscle) to play a, relatively, increased role in future sprinting ability (Bosco et al., 1986). The physical changes to the exercising muscle coupled with neuronal adaptations, which allow for more efficient use of the sympathetic nervous system, may allow for enhanced sprinting ability after longitudinal use of resisted-sprinting techniques.

By comparison, acutely implemented resisted sprinting techniques, which aim to cause a post-activation potentiation (PAP) effect after a single trial, may enhance power-dominant performances, such as sprint-running due to short term neurological, and to a lesser extent physical, changes which can serve to increase the rate of force development of the exercising skeletal muscle (Hodgson et al., 2005; Tillin & Bishop, 2009). These factors, which may serve to enhance subsequent power-dominant performances, will be presented in greater detail in the section to follow. Choosing a resistance in order to achieve PAP can be tricky because several factors must be taken into account in order to achieve performance enhancement, through PAP, in a subject. Fatigue, training level, strength, and predominant muscle fiber type are all factors to consider when trying to induce a PAP effect in a subject so that subsequent athletic/physical, power-dominant, performances may be enhanced. The reasoning behind the consideration of these factors will be explained in greater detail later in this document. The basic underlying issue in determining a resistance load has to do with two primary factors; (a) fatigue caused by the loading, and (b) recovery from the sustained fatigue (Chiu et al., 2004; Tillin & Bishop, 2009).

Any sort of exercise causes neuromuscular fatigue, and power-dominant exercises, such as sprint-running, can be particularly fatiguing. It is no surprise, then, that exercise which stresses the muscle to a point of maximal, or near maximal, contraction (that is to mean maximal or near maximal motor unit recruitment of a muscle) will cause a great deal of fatigue. This means that the loads used in exercises which are implemented to cause PAP require a rest period in which fatigue can subside but the benefits of PAP remain. What this means is that, even if a resistance load is a sufficient stimulus to help create the PAP effect, the rest period which follows this loading must be optimal. A rest period which is not long enough in duration means that the subject may be too fatigued to show any performance enhancement in subsequent trials which follow the loading. If the rest period is too long in duration, following the loading, then the individual may have lost the effects of the PAP, and again, the subsequent trials will probably show no significant signs of enhanced performance. Only two studies have implemented resisted sprinting methods in an attempt to induce PAP and both have been successful in their attempts to enhance sprinting performances (Matthews et al., 2010; Smith, 2012). PAP has also been seemingly induced by methods such as squatting and the snatch lift (one of the Olympic style weightlifts), or a variation of this lift (Chiu et al., 2003; Chiu & Salem, 2012; McBride et al., 2005). Following the implementation of the methods in these studies, sprint-running and jumping performances were enhanced. Although the study to be proposed will not employ these methods to induce attempt to induce PAP, these are still important studies to review because they are studies which show that PAP may be a viable means of enhancing power dominant performances.

Despite the fact that the possible physiological mechanism’s underlying PAP have been studied in great detail the last decade plus, it is still unclear which mechanism, or combination of mechanism’s, may have the greatest effect on the enhancement of sprint performance, it is also unclear how substantial the PAP effect may be in actually enhancing power-dominant performances such as such as sprint-running (Hodgson et al., 2005). Before studying the possible underlying mechanisms of PAP, it is imperative to have a better understanding of what PAP actually is, and why so many researchers believe that PAP may play a role in the enhancement of power-dominant athletic performances.

What is Post-Activation Potentiation?

As has been already presented in this document, post-activation potentiation occurs after skeletal muscle has been contracted maximally or near maximally. Many Researchers have theorized, and some studies have shown, that potentiated muscle tissue may have an increased rate of force development when compared to the same muscle tissue in an unpotentiated state (Chiu et al., 2003; Chiu & Salem, 2012; Hamada et al., 2000; Hodgson et al., 2005; Jo et al., 2010; Kilduff et al., 2007; Matthews et al., 2010; Ruben et al., 2010; Yetter & Moir, 2008). Although the reasons for this increased rate of force development are not completely understood at this time, changes in “twitch” contraction responses of muscle have been observed. Twitch contractions are brief muscle contractions caused by a single pre-synaptic action potential, or by multiple action potentials which are all transmitted simultaneously (Hodgson et al., 2005). The observed changes in the twitch response, after potentiation, are an increased rate of force development as well a reduction in time needed to reach peak force (Hamada et al., 2000; Szczesna et al., 2002). The changes in twitch contractions after a potentiation stimulus are, for all intents and purposes, what post-activation potentiation is. Although we know that changes in twitch contractions occur after potentiation, it is not entirely clear why they occur. Furthermore, it is not entirely clear why some studies have seemingly shown enhancements in athletic performances after potentiation methods, while others have not, even though twitch potentiation is unequivocally known to occur and is reproducible (Hamada et al., 2000; Hodgson et al., 2005). Many possible reasons exist about why there seem to be inconsistencies in the findings of potentiation studies with regard to their effect on athletic performance. The training state of participants, muscle fiber type of participants, and the variables (such as rest times and loading methods and intensities) of the set-up of a research study are just a few factors which can play a role in the findings of studies which attempt to acutely enhance power-dominant athletic performance (Chiu et al., 2004; Hodgson et al., 2005). Whatever the reasons for the inconsistencies among the findings of these studies, there are compelling theories which seem to explain the causes of PAP. These underlying theories, which seem to explain how potentiation of skeletal muscle occurs, will be explored next in the section to follow.

Post-Activation Potentiation: The Physiological Causes

The literature pertaining to post-activation potentiation generally points to two physiological mechanisms which seem to be responsible for causing post-activation potentiation. These physiological mechanisms are, (a) the phosphorylation of myosin regulatory light chains, and (b) an increase in the recruitment of higher order motor units. (Hodgson et al., 2005; Tillin & Bishop, 2009; Szczesna et al., 2002). However, at this time, it is unclear which one of these mechanisms plays the greatest role in causing PAP.

In order to understand how PAP has the potential to enhance power-dominant athletic performance, we must examine these mechanisms. We will start by examining the phosphorylation of myosin regulatory light chains.

Myosin regulatory light chains (RLC's) attach myosin heads to the myosin heavy chain, which is a double helix shape and serves as the "backbone" of the myosin molecule (Sweeney, Bowman, & Stull, 1993; Seeley, Stevens, & Tate, 2008; Tillin & Bishop, 2009). Each myosin head is attached to two myosin light chains. Each myosin light chain contains a binding site for a phosphate group. As calcium is released to cause muscle contraction, some of these calcium ions attach to a protein called calmodulin. The calcium ions which are attached to calmodulin are able to activate the enzyme known as myosin light chain kinase. Myosin light chain kinase transports phosphate molecules from spent ATP to the phosphate binding sites on the myosin light chains. It is in this process that the myosin RLC's become phosphorylated. The phosphorylation of myosin regulatory light chains also results in the altering of the shape of myosin heads (Hodgson et al. 2005; Tillin & Bishop, 2009). Altering the shape of the myosin heads allows these myosin heads to pull further away from their heavy chain "backbone" making it easier for cross-bridging to occur. It seems that the phosphorylation of myosin RLC's also increases the mobility of myosin heads (MacIntosh, 2003). This combination of increased myosin head mobility coupled with the fact that myosin heads seem to be in closer proximity to actin means seems to explain the increased rate of force development of skeletal muscle due to phosphorylation of myosin RLC's.

Another effect which occurs due to the phosphorylation of myosin RLC’s, and it has been suggested that this may be the most important effect of Myosin RLC phosphorylation (Hodgson et al., 2005; Hamada et al., 2000; Szczesna et al., 2002, Tillin & Bishop, 2009) is the effect of skeletal muscle to becoming more sensitive to calcium. This increased sensitivity to calcium allows calcium to bind with troponin, exposing myosin head binding sites on actin. It should be noted that this increased sensitivity to calcium only seems to occur when calcium concentrations of the muscle are relatively low, which is the case when a muscle which has recently experienced recent maximal or near maximal contraction (Hodgson et al., 2005; Hamada et al., 2000; Szczesna et al., 2002; Tillin & Bishop, 2009).

It should be also said that the maximal or near maximal contraction of a skeletal muscle occurs due to a stimulus which is strong enough to cause contraction of nearly all, if not all, of the motor units in a muscle (Hodgson et al., 2005; Hamada et al., 2000; Szczesna et al., 2002; Tillin & Bishop, 2009). This simply means that a great enough amount of muscle tissue in a given muscle has had almost all of its myosin RLC’s phosphorylated. This maximal contraction can leave muscles in a phosphorylated and potentiated state. This also leaves muscle in a state in which it contains relatively low calcium levels. However, as mentioned before, the low calcium levels may not play a great factor in reducing the ability of muscle to contract because the phosphorylated RLC’s render the muscle more sensitive to the effects of calcium. Interestingly, the process of myosin RLC phosphorylation plays a key role in the normal contraction of smooth muscle, but it does not play a key role in the normal contraction of striated (like skeletal) muscle unless this type of muscle has experienced recent maximal or near maximal contraction (Seeley et al., 2008, Sweeney et al., 1993). This is because too few myosin RLC's, of the skeletal muscle, have been phosphorylated to allow RLC phosphorylation to be a key mechanism which aids in skeletal muscle contraction. Although phosphorylation of myosin regulatory light chains undoubtedly plays a key role in the potentiation of skeletal muscle, it probably is not the sole mechanism, relating to potentiation, which may act to enhance the performance capabilities of skeletal muscle (Tillin & Bishop, 2009). As was mentioned earlier, the increased recruitment of higher order motor units is another mechanism which seems to play a critical role in the enhancement of muscle performance (Hodgson et al., 2009; Tillin & Bishop, 2009). How these motor units are recruited and how it all plays a role in the possible enhancement of speed-strength performances will be explored next.

A motor unit is the combination of a motor neuron and all of the muscle fibers which that motor neuron innervates (Kandel, Schwartz, & Jessell, 2000; Seeley et al., 2008). A motor unit contracts when a threshold stimulus is met, this allows a potential to be propagated, causing all of the muscle fibers of that motor unit to be contracted. Normally, muscle fibers are contracted in order of smallest to largest in a theory sometimes known as the size principle (Kandel et al., 2000; Ross et al., 2001; Seeley et al., 2008). Smaller (type I) muscle fibers generally have a greater capacity, than type-II muscle fibers, to sustain, predominantly, aerobic exercise and, as such, are innervated with smaller motor neurons than their larger fiber counterparts. The threshold which needs to be met, in order to cause contraction of type-I muscle fibers, is less great than that type-II muscle fibers. As one would expect, muscle fibers make up is a continuum, so to speak, in which ever larger muscle fibers contain fewer and fewer mitochondria and have an ever increasing ability to metabolize substrates anaerobically. This also means that these larger muscle fibers are innervated by larger motor neurons than are smaller muscle fibers. What this all means is that, in order for higher order (larger, type-II) muscle fibers to be contracted, the strength of the stimuli must be greater than that which causes the contraction of smaller motor units. This increasing stimulus strength causing more, as well as larger, muscle fibers to be contracted is, in effect, what the size principle is.

When referring to skeletal muscle and, specifically, the recruitment of higher order motor units, it is imperative to have basic understanding of the workings of a chemical synapse and the factors which can increase the number of excitatory potentials that allow skeletal muscle fibers to contract. In a chemical synapse, we have three primary parts, which are (a) a pre-synaptic terminal; (b) a synaptic cleft; and (c) a post-synaptic membrane (Purves et al., 2001; Seeley et al., 2008). The pre-synaptic terminal is at the end of the axon of a neuron where the terminal buttons are located. The synaptic cleft is the space between the pre-synaptic terminal and the post-synaptic membrane. The post-synaptic membrane is the membrane of the cell which interacts with the pre-synaptic terminal (which is part of a larger cell). The two cells on either side of the synaptic cleft interact with each other via neurotransmitters which are released from the pre-synaptic terminal and into the synaptic cleft. After release, some of the neurotransmitter becomes bound to receptors on the post-synaptic membrane.

In the case of potentiation and causing skeletal muscle to contract, the neurotransmitter which is released binds to its specific receptors on the post-synaptic membrane (Seeley et al., 2008). When binding to a muscle cell membrane, in order to stimulate contraction, the neurotransmitter (most likely acetylcholine) would likely open sodium channels allowing for depolarization of the membrane. This depolarization is stimulatory, and is known as an excitatory post-synaptic potential (EPSP). These EPSP's, as they are known, can cause the membrane to reach threshold, and once this threshold is met, an action potential is created which could cause a muscle cell, or cells, to respond by contracting. Chemical junctions and EPSP's are not found solely at neuromuscular junctions. They are also vital to the normal functioning of neuron to neuron (neuronal) junctions, as well as to the functioning of glands and the neurons which interact with them (Seeley et al., 2008; Tillin & Bishop, 2009). No matter the type of junction, the important thing to know is that EPSP's increase the likelihood for action potentials to be produced causing post-synaptic cell response (Seeley et al., 2008; Ross et al., 2001). Now that some light has been shed on the importance of EPSP's, we can better understand why it is suggested that the recruitment of higher order motor units may play a key role in causing post-activation potentiation.

Some animal studies have shown that tetanic muscle contractions have the ability to increase the number of excitation potentials which occur at synapses of the spinal cord (Tillin & Bishop, 2009). Furthermore, several human studies have had some success in enhancing the performance of muscular speed-strength performance following the implementation of maximal voluntary isometric contraction (MVIC), which is used as a means of inducing potentiation (Hamada et al., 2000; Stuart, Lingley, Grange, & Houston, 1988). The thought behind the enhancement of the muscular speed-strength performance in these studies can be tied to the findings of the animal studies which were mentioned earlier. The thought is that, tetanic contractions which enhanced subsequent muscular speed-strength responses in the human studies which implemented MVIC, and the animal studies which were able to increase excitation potentials at the spinal cord after skeletal muscle tetanic contractions (caused by way of electrostimulation), would almost certainly increase the amount of neurotransmitter released at the level of the spinal cord which could increase the number EPSP's at motor neurons which control higher order motor units. As the number of EPSP's increases, then the likelihood of increasing the recruitment of higher order motor units also goes up. However, no matter the means of inducing potentiation, whether it be, (a) MVIC; (b) weight lifting; (c) resisted sprint-running; or (d) any method, for that matter, rest still plays a key role in the muscular response which is subsequent to the induction of potentiation. With regard to what has been talked about in the portion of this review regarding the increased recruitment of higher order motor units, this rest may be important, in part, because it allows receptors of neurotransmitters on the pre-synaptic terminal to be cleared, allowing for greater neurotransmitter release (Seeley et al., 2008). The fact is, the post-synaptic membrane is not the only portion of a chemical synapse which contains receptors for neurotransmitter, so too does the pre-synaptic terminal. Even after excitatory neurotransmitters have been released, some will, for a time, bind with receptor sites on the pre-synaptic terminal. If this happens, then the release of those or other specific neurotransmitters may be reduced because many of the sites from which they would be released would become effectively blocked, at least for a time (Seeley et al., 2008).

At least some combination of the phosphorylation of myosin regulatory light chains and the increased recruitment of higher order motor units seem to contribute, in large part, to the possibility of enhanced speed-strength performances as a result of the induction of post-activation potentiation. Several studies have attempted to study PAP, and a few have seemed to be successful in showing that PAP may allow for the enhancement of speed-strength performances, but a large number of studies which try to induce PAP for the benefit of subsequent speed-strength performances have had mixed results. These mixed results may be due to the fact that studying PAP, in a setting where the goal is to enhance physical performance, is very difficult for a number of reasons, reasons which will be explored in the following sub-section.

The Difficulties in Studying PAP for the sake of Enhancing Speed-Strength Performances

Despite the fact that post-activation potentiation is a very real phenomenon which has the potential to enhance speed-strength performances, the results of studies which attempt to induce PAP for the sake of enhancing speed-strength performances are mixed (Hamada et al., 2000; Tillin & Bishop, 2009). These mixed results could be due to a number of reasons, the most obvious reasons which are usually given are, (a) research design flaws, and (b) participant characteristics. The idea of inducing PAP is simple enough. Most studies try to implement some sort of external resistance which attempts to elicit maximal or near maximal muscle contraction of the muscles to be potentiated. Secondly, adequate rest time, following the implementation of resistance, must be given so that the subsequent speed-strength activity performed by the subjects is not overshadowed by fatigue. This seems simple enough, but, if the rest period is too short, than any gains which may have otherwise been observed due to a potentiation effect may be negated by fatigue. On the other hand, if the rest period is too long, then a subject, who once had enough muscle mass in a potentiated state to cause an enhancement of a subsequent speed-strength performance, may no longer have much muscle tissue in a potentiated state. Lastly, if the resistance does not cause enough muscle tissue to be stressed to a great enough degree, or for a long enough period of time, then the subject may not achieve potentiation of enough muscle tissue to see any effect in a subsequent speed-strength performance.

The physical make-up of subjects who participate in potentiation studies also seems to play a significant role in the outcomes of the potentiation studies. It seems that the type of muscle which has the greatest degree of response to potentiation is type-II (fast-twitch) muscle fibers (Hamada et al., 2000; Ross et al., 2001). If this is indeed the case, then even if all else was equal among the subjects, (i.e. nutrition, sleep patterns, training state, etc.) then it would seem that, in general, those who had a the greater muscular make-up of fast-twitch muscle fibers would be the greatest responders to the different potentiation methods which have thus far been studied. Unfortunately, it is very difficult, if not impossible, to control the factors such as nutrition and sleeping-patterns of each individual who participates in a potentiation study. As was mentioned earlier, the best subjects for a potentiation study are, generally, those with a greater number of fast-twitch muscle fibers. In layman's terms, at least in terms of sprint-running potentiation studies, ideal participants have a fast top-end running speed, and they can get to that top end running speed in a relatively short period of time. However, participants such as these are often active in athletic competitions and training for competition. This means that these participants may not be able to follow the rest protocols that other participants of a potentiation study may be more easily able to follow. Only a few of the myriad of possible confounding factors, surrounding the outcome of a potentiation study, have been presented in this paper, but these examples make it evidently clear as to how findings from, otherwise solid, research protocols can be skewed due to factors which are beyond the control of the researcher.

All of that said; it is very important to take into account not only the findings of potentiation studies, or the findings of any other study, for that matter, but it is also important to be aware of the some other factors as well. Variables such as, (a) the "type" (sprint athletes vs. endurance trained athletes) of individuals who participate, (b) the training status of those individuals, and (c) rest protocols which were implemented during the course of the study. All of these variables give us a better picture of what the results are actually telling us.

Now that potentiation and its primary mechanisms have been defined, and since the difficulties of studying the phenomenon known as post-activation potentiation have also been identified, it is possible begin to take a look at some of the literature surrounding PAP. The results of human performance studies which have tried to induce

PAP, for the sake of enhancing speed-strength performances, have been mixed (Hamada et al., 2000, Tillin & Bishop, 2009). Although the results of the studies, as a whole, have yielded mixed results, the findings of several individual PAP studies seem to indicate that a variety of methods can be used to effectively enhance subsequent speed-strength performances. Furthermore, the success of PAP studies may have as much to do with the type (sprint vs. endurance) of participants in the study than any other factor (Hamada et al., 2000). A foundation for the study to be proposed will be laid by taking a close look at studies which seem to make a case for the induction of PAP for speed-strength performance enhancement via the acute use of different resistance methods. It will also be speculated as to why these studies may have been successful in showing a performance enhancing effect.

Finally, we will take a look at where the information surrounding PAP studies and the enhancement of physical speed-strength performances are lacking, and how the study to be proposed will hope to further the information base from which future researchers, and coaches, can draw from.

Methods Which Have Been Used In Order to Generate a PAP Response

In Past studies, researchers have attempted to induce PAP in subjects with the use of (a) heavy-load squatting, (b) Olympic lifting (power-snatch), (c) Ballistic bench press throws and (d) Heavy resisted sprinting techniques (Alcaraz et al., 2008; Alcaraz et al., 2009; Bennett et al., 2009; Bosco et al., 1986; Clark et al., 2010; Jo et al., 2010; Harrison & Bourke, 2009; Kristensen et al., 2006; Lockie et al., 2003; Matthews et al., 2010;

Maulder et al., 2008; McBride et al., 2005; Paulson & Braun, 2011; Spinks et al., 2007; Yetter & Moir, 2008; Smith, 2012). The findings of some of these studies indicate that the potentiation caused by these methods can enhance speed-strength performances, and sometimes, this enhancement is statistically significant. We will begin by examining studies which have implemented heavy-load squats as a means by which to induce post-activation potentiation, and subsequent enhancement of speed-strength performances.

Heavy-Squat Loading and Post-Activation Potentiation

Several studies have seemed to successfully implement squatting techniques which have elicited a PAP response that has allowed for an increase in subsequent speed-strength performances (Jo et al., 2010; Kilduff et al., 2007; McBride et al., 2005; Ruben et al., 2010; Yetter & Moir, 2008).

A study conducted by Yetter and Moir (2008) used heavy back squatting and front squatting (which were performed to a depth when the femur was parallel to the floor; commonly known as a half-squat) as methods by which to attempt to induce PAP in an attempt to enhance subsequent 10-meter sprint-runs. The front and back squatting potentiation induction methods were compared to just sprint-running alone, another method by which to attempt to induce PAP. The subjects in the study were strength trained college athletes whom participated in football, weightlifting and track and field sports. Interestingly, the authors found that the fastest running speeds occurred following the heavy back squat session, which had the athlete-participants lift with weight as high as 70% (for three repetitions) of their one repetition maximum (1RM) for a [half] back-squat. The running speed after performing these back squats was significantly faster than those which were correlated with the running speeds of the other two conditions. The authors found that the front-squats were correlated with the slowest running speeds of the three conditions. This finding is curious, based on the findings of, Stuart, Meglan, Lutz, Growney, and An, (1996) who has shown that front and back squats can engage an almost equal amount of knee extensor musculature. However, the findings of the Yetter and Moir (2008) study could be explained by the physiological mechanism's which, as explained in the "Post-Activation Potentiation: The Physiological Causes" section, are linked to maximal, or near maximal skeletal muscle contraction. This maximal, or near maximal, contraction may not have been achieved during the front squat due to the fact that the Yetter and Moir (2008) estimated the 1RM of the front squat at 80% of the back squat 1RM. This estimation of a 1RM was the only difference between the two squatting conditions, all the rest of the parameters (relative intensities, rest times, etc.) were the same. This means that it is probable that too much fatigue was induced, from the front squat, without the added benefits of rendering increased amounts of muscle tissue more sensitive to calcium via the phosphorylation of myosin regulatory light chains. It is also possible that the front squat protocol did not cause much of a change in the way of increasing higher order motor unit recruitment via significantly increased neurotransmitter release. The findings of this study are similar to those found by McBride and colleagues (2005).

Similar to the Yetter and Moir (2008) study, McBride and colleagues (2005) also used a heavy-load squat protocol in an attempt to induce potentiation with the hopes of enhancing subsequent 40-meter sprint-run trials. The subjects of this study were all college football players who were all part of the same strength and conditioning program. Like the Yetter and Moir (2008) study, this study also compared the three different conditions had on subsequent 40-meter sprint times. All of these conditions had the same warm-up followed by four-minutes of active-rest (walking). The heavy back squat condition consisted of three repetitions with 90% of each individual's one repetition maximum (1RM) for the back squat exercise. The second condition was a maximal effort countermovement jump squat, performed on a modified smith machine, with a resistance equal to 30% of each individual's one repetition back squat maximum. The third condition, which acted as the control, was the standard warm-up which was also observed during the other two conditions. Following each condition, the subjects observed the four minute active recovery period. Following the four minute recovery period the subjects ran one 40-meter sprint per condition, starting from a three point stance, which were electronically timed at the 10, 30, and 40 meter marks. Once again, the authors found that the greatest effect on subsequent sprint running times came after the performance of heavy back squats. In fact, based on the times recorded at the 40-meter mark, the sprints which were performed after the heavy back squats were significantly faster than those sprints which were performed after the control condition. The loaded countermovement squat jump also correlated with faster sprints than the control condition; however, none of these times were significantly statistically faster than the control. Maybe the most interesting part about this piece of research is the fact that the McBride and Colleagues (2005) took this research a step further by splitting the participant information up in the strongest (n=7) and weakest (n=8) groups, based on the 1RM back squat of each individual with regard to each individual's bodyweight. Not surprisingly, the researchers found that the mean results of those in the strongest group performed significantly (statistically) better on all of the post-condition sprints when compared to the mean results of the weakest group. However, an intragroup look at the differences of the mean sprint times which correlated with the experimental conditions and the control condition were not significantly different. It is also worth pointing out that an intergroup analysis of mean time differences between the experimental and control conditions showed no difference in time change, through 40-meters, between either of the groups, with regard to each condition. However, both within each of the strongest and weakest groups, the heavy squat protocol was correlated to the greatest difference in average sprint time, through 40-meters, when compared to the sprint times, through 40-meters, after the implementation of the control condition and the countermovement squat jump condition. This research nicely complements the findings of Yetter and Moir (2008) in showing that a squat protocol may be a viable warm-up option in an attempt to enhance subsequent sprint-running performances.

Much like Yetter and Moir (2008) and McBride and colleagues (2005), Ruben et al. (2010) also showed that the squat may be a viable option by which to enhance subsequent power-dominant performance. However, the Ruben et al. (2010) study attempted to enhance horizontal jumps, rather than sprint-running. Unlike the other studies, the Ruben et al. (2010) participants were recreationally trained men, all of whom were able to back squat at least one and one-half times their body weight. This study implemented a squat protocol which had the individuals squat with weight as high as 90% of their individual one repetition maximum's for three repetitions. The squats were followed by five minutes of rest. The control condition consisted of a standard warm-up, which was used for both conditions of the study; followed by five minutes of resting. After the rest periods of each condition, the subjects performed a series of five hurdle jumps in which an accelerometer was used to measure; (a) peak power output, (b) peak velocity, and (c) peak force. The researchers found that the average peak force for all five of the jumps was significantly higher following the back squats (potentiation) session when compared to the average peak force across the five jumps during the control session. Concurrently, although not statistically significant, the researchers found that the maximal peak force and peak power outputs of the jumps, following the back squats session, were also greater than that the maximal peak force and peak power outputs found during the control session. This study is another example which demonstrates that heavy-load squatting, used to induce potentiation, can be a beneficial warm-up method by which subsequent speed-strength performances may be enhanced. The final study which will be examined in this section, also measured a jumping task after the performance of heavy-load squatting.

Kilduff et al. (2007) studied how squatting affected the task of countermovement jumping. The participants in this study were professional rugby players who had been part of a regular strength and conditioning program for at least 1.5 years. This study is a bit different than the others, however, because of the fact that it attempted to find the optimal recovery time following the implementation of the possible potentiation stimulus (the squats). First, a warm-up was performed; this was followed by a baseline countermovement jump. This countermovement jump was performed with a broomstick across the shoulders (to simulate the squatting position). A "ballistic measurement system" was attached to the broomstick to measure peak power output during the jump. Following this warm-up and jump, the subjects performed back squats through a full range of motion for sets of three, and five minutes rest were taken between each set. The weight was increased for each set thereafter until the subject failed to complete the three repetitions of squatting through the full range of motion. Immediately after the failed squat set, the subjects performed a countermovement jump using the same methods as the baseline jump. The subjects then completed one jump at four-minute intervals for up to 20 minutes and, again, the power output data was collected for each jump. The authors found that, on average, the greatest increases in power output occurred at eight and 12 minutes following the stimulus (squats). Both of these increases were statistically significant. Furthermore, the jump which occurred at the 12 minute mark, post-stimulus, resulted an almost 8.0 % increase in power output when compared to the baseline jump.

Here we can see that, once again, squatting may be a viable option in increasing power output. This study also presents the idea that proper rest periods are critical in maximizing the effect following a potentiation stimulus. As was mentioned earlier, heavy-load squatting isn't the only method which has been implemented to enhance subsequent speed-strength performances, next we will examine studies which have successfully implemented Olympic and ballistic "power-lifting" variations of resistance in order to enhance speed-strength performances.

Enhancing Speed-Strength Performances through the Use of Olympic and "Ballistic Power-Lifting" Variations of Resistance

Radcliffe and Radcliffe (1996) studied the effects which various methods which could possibly cause potentiation had on subsequent horizontal jumping tasks. What was found during this study was that the greatest jump distances occurred after the performance of the power snatch exercise. A total of 35 subjects, who were recreationally trained, participated in this study; 24 of these subjects were male. The findings of this study showed that the power snatch performance prior to the horizontal (unloaded) countermovement jumps had the greatest effect of any of the exercises, which included, (a) the power-snatch, (b) the back squat (four repetitions @ 75-85%), (c)loaded countermovement jumps with 15-20% of body mass as external resistance, & (d) just the standard warm-up (as a control). To add more clarity to the findings, when performing the power snatch, the males in the study experienced significantly increased jumping distances when compared to their jumps during the control condition. Furthermore, it should also be noted that all of the conditions in this study, for both men and women, which used some sort of external resistance, correlated with greater horizontal jump distances than just the standard warm-up.

Kilduff et al. (2007) also studied an upper body potentiation technique with the same 23 professional rugby players whom had participated in the portion of their study which included the use of squats as a means of enhancing a series of countermovement hurdle jumps. For the upper body, the method which was used to attempt to induce potentiation was the bench press throw which was performed on a modified smith machine. Much like the lower body testing, all of the subjects performed a standard upper-body warm-up followed by a bench press performance which had the individuals perform sets of three repetitions until each individual reached a three-repetition maximum. A period of five minutes of rest was given between each set, and once and individual's three repetition maximum was found for the testing day, the individual immediately performed a bench press throw, on a modified Smith Machine with 40% of their three repetition bench press maximum. Every four minutes thereafter, the participants performed one bench press throw for a time up to 20 minutes following the final set of the bench press performance. The results of this study showed that the bench press throws at eight, 12, and 16 minutes following the final set of bench press showed statistically significant increases in power output, when compared to the baseline values. The greatest average increase in power output was a 5.3% increase which came at 12 minutes post-bench pressing. Here, again, is another example which shows that the rest time which follows a possible potentiation stimulus is a critical variable when hoping to optimally enhance subsequent power-dominant performances due to the effects of PAP.

The final method of post-activation potentiation induction which will be explored in this review is the heavy resisted sprint. Although resisted sprinting has been studied a great deal over the last decade plus, very little research has actually been conducted on the acute effects of heavy resisted sprinting with regard to its possibility to enhance subsequent sprint performances via potentiation. The majority of resisted sprinting research has focused on longitudinal use of resisted sprint methods in order to study how sprinting kinematics are, or are not, altered, and/or how sprint-running speed changes over a period of several weeks with the regular use of resisted sprinting techniques. It is in this light, we will look at the research which surrounds the idea of resisted sprinting and its possible effects on enhancing sprint-running performance through the induction of post-activation potentiation.

Resisted Sprinting and Post-Activation Potentiation

At this point in time, there are only two studies, which the author of this review is aware of, which have attempted to use heavy resisted sprinting as a means of inducing post-activation potentiation in an attempt to enhance subsequent sprinting performances. To make matters even more interesting, one of these studies did not involve sprint-running; this study was performed on ice, involving hockey players in hopes of acutely enhancing their sprint-skating performances (Matthews et al., 2010) and this is the study which will be examined next.

Matthews and colleagues (2010) studied the effect that resisted ice-skate sprinting had on subsequent unresisted ice-skate sprints. The participants of the study were professional hockey players. Before each of the two conditions, the participants performed the standard warm-up. The control condition consisted of the warm-up followed by a 25-meter skate-sprint performance (pre-test). This was followed by four minutes rest, and then a re-test of the 25-meter skate sprint. The experimental condition followed the same procedure, except, following the pre-test, the participants rested for one minute, and then performed a resisted skate-sprint in which they were tethered to a man, wearing full hockey gear, who resisted their sprint effort. Following the resisted sprint, the subjects rested for four minutes. Following the rest, the subjects performed another unresisted 25-meter skate-sprint. The data from this study showed that the mean control condition sprint times increased from pre- to post-testing. The experimental condition showed a mean decrease in in the post-test sprints when they were compared to the mean time of the pre-test sprints for that day. Furthermore, this mean time decrease following the experimental condition was found to be statistically significant.

The Matthews et al. (2010) study is interesting because it is the first to use a resisted sprinting technique as a means of acutely enhancing subsequent sprint performances. Although this study was performed with ice-skate sprinting, it seems reasonable to think that a similar resisted sprint study could be performed with participants who are sprint-running instead of skating. In fact, just such a study was recently performed by Smith (2012).

In the Smith (2012) study, a group of 24 anaerobically trained men and women performed four different warm up conditions in an attempt to induce PAP with the hope of effecting subsequent sprint running times. Each condition was performed on a different day. All of the conditions involved a standard warm up followed by four minutes of active recovery, followed by an electronically timed, unresisted, 40-yard sprint (pre-test sprint). Three of the conditions implemented sled-pulls (at 10%, 20%, and 30% of each individual's body mass) through 20-yards, as a method of resistance, while the fourth condition was a 20-yard, unresisted, sprint run. All of the 20-yard sprints were video recorded between the beginnings of the 10-yard to the beginning of the 11 yard marks so a kinematic analysis could be made. All of the four conditions were followed by four minutes active recovery which was followed by a post-test 40-yard sprint. What the Smith (2012) study found was that the greatest resistance load condition (30%) coincided with the greatest reduction in sprint times (by 2.24 %) from pre- to post-test runs. What is also intriguing about the findings is that the next greatest average reduction, from pre- to post-test sprint times occurred following the unresisted running condition. This finding corresponded with a 2.14% reduction in sprint times, on average, from pre- to post-testing. The 20% loading condition corresponded to a 2.11% average reduction from pre- to post-test sprint times, while the 10% load showed a 1.21% reduction from pre- to post-test sprint times, on average.

These findings are intriguing because we see that the 10% load is within the range of recommended sled-pulling resistance loads for resisted sprint training (Alcaraz et al., 2009; Bennett et al., 2009; Lockie et al., 2003; Maulder et al., 2008; Paulson & Braun 2011; Spinks et al., 2007), but, curiously, this load seemed to be the least effective of the four trials. A logical explanation for this result may very well have to do with the PAP-fatigue effect that was alluded to earlier. It could very well be that the 10% load was not sufficient enough to potentiate the amount of muscle needed to enhance the subsequent sprint performance. At the same time, the 10% external load could have caused enough fatigue (again, without causing a great deal of potentiation) so that, in comparison to the unresisted sprinting condition, the percent decrease in subsequent sprinting time was not as great. In short, the results of Smith (2012) study leave the door open to the possibility that towing heavier resistance loads during a sprint may result, acutely, in greater enhancement of subsequent sprint-running trials.

Also important to note is that, when compared to the unresisted condition, both the 20% and 30% (the greatest kinematic changes occurring during the 30% load) loads significantly altered sprint kinematics in both hip and shoulder flexion, when compared to the unresisted condition. However, the average sprinting times for these two times were not significantly different than that of the unresisted run, or that of the 10% load. This may indicate that these altered techniques are short term adaptations resulting from the overloading and that they do not carry over to the subsequent unloaded sprint. This may also indicate that the greatest factor influencing a change in sprinting speed is strength and not running kinematics.

With that information put forth, it can be seen that sufficiently overloading an athlete with resisted sprint training may be the best way in which to acutely help increase force output with each step. Next, a proposal for a research study will be presented, by the author of this review, so that the issue of resisted sprinting may be further studied.

CHAPTER III

METHODOLOGY

The purpose of this study was to determine how several different sprint training conditions affect subsequent sprint-running performances. The participants of this study performed three different sprint-running conditions, each of which occurred on a separate day. Two of these conditions involved a heavy sled-pulling condition, while the third condition involved only unresisted sprinting. Each sled-pulling condition involved three, 30-meter, sprints. Two of the sprints of each of the two sled-pulling conditions were electronically timed, these two timed sprints were unresisted and they were the pre-testing and post-testing sprints which occurred, respectively, before and after the heavy sled-pulling conditions. The unresisted condition involved one, 30-meter, electronically timed, pre-testing sprint, followed by one, 30-meter, electronically timed, post-testing sprint. The pre- and post-testing differences in sprint times within, and between, each condition, were compared and analyzed in an attempt to explain why each difference between pre- and post-testing runs occurred and how this could have been affected by PAP, fatigue, and kinematic alterations.

Research Design

This study implemented a repeated-measures quasi-experimental design. This means that every participant in the study performed each of the three conditions and that the subjects were part of a convenience sample. The order in which the participants performed each testing session was counter-balanced. The independent variables were sled-pulling or the unresisted sprinting pre-test of the unresisted day. The dependent variables were the sprint times of the post-testing sprints.

Research Participants

Fifteen participants were selected based on their training history. Participants were males (n = 11; age 23.3 ± 1.8 years) and females (n = 4; age = 23.0 ± 3.2 years) who were either, recreationally trained, division I collegiate athletes, or strength and conditioning coaches, all of whom regularly used sprint training as part of their normal physical training programs. Prior sprint training experience was vital to ensure that participants would give maximal effort through the course of each sprint. Injury or any other condition which prevented any participant from performing sprint-running excluded that individual, or those individuals, from continued participation in the study. Prior to any data collection, all participants reviewed and signed an informed consent document. The Institutional Review Board approved all of the testing procedures of this study.

Instrumentation

All of the resisted sprinting trials implemented the use of a sled which weighs 50 pounds. All extra weight which was added to the sled was added with the use of weightlifting plates. When pulling the sled, each participant wore a chest harness which had a tether that connected the harness to the sled. All unresisted sprinting times were recorded using a Brower brand timing system (Brower Timing Systems, Draper, UT, USA, 84020). All statistical analyses were made using Microsoft SPSS software Version xx (Microsoft Corporation, Redmond, WA, USA, 98052). All body weight measurements and height measurements were made with the use of a physician's digital weighing scale.

Procedures for Collecting Data

Prior to any testing, those interested in participating were explained the procedures which were to take place on the testing days. Those who were still interested in participating in the study were then asked to read and sign an informed consent document. After this, height and weight measurements were taken in the athletic training room at the University of Northern Iowa. The participants did not wear shoes during their measurements of height or weight. All data collection and testing, thereafter, took place on the artificial field-turf surface at the indoor football stadium at the University of Northern Iowa. Brower brand electronic timing gates were placed at the 10-meter, 20-meter, and 30-meter marks of the running lane which was outlined with athletic tape. At the starting line, which was also marked with athletic tape, the participants started in either a three-point, or four-point, starting stance (each participant was encouraged to use the starting stance which he or she was most familiar with) with one thumb placed on a thumb pad. The removal of a participant's thumb from the thumb pad resulted in starting of the timer so that the sprint could be timed. Each participant was also instructed to give maximal sprint-running effort for each of the time-measured sprints. No extra verbal encouragement or suggestions were given to the participants during, or following any of the sprints.

Prior to all testing, the participants each performed a standardized warm-up. The warm-up included four-minutes of light jogging, followed by quadriceps stretches in which the participants walked ten-yards and after each step extended the hip while pulling the heel of the foot toward the glutes. Next came a glute/hamstring stretch in which the knee was pulled toward the chest, again, this was performed while walking a distance of 10-yards. Next, the participants performed unweighted walking Romanian Deadlifts (RDL's) over a distance of 10-yards. The walking RDL's were followed 10-yards of walking lunges with a slight trunk twist. Twenty jumping jacks followed the RDL's. Next, five-yards of quick skips were performed, which was followed by five-yards of high skips. The participants then performed five-yards of rotary running.

Next, the participants were given six-minutes in which to do anything else which they felt may be necessary to prepare for the sprint running trial to follow. This was followed by the performance of three sprint starts from the starting stance of their choice; each of these was run for 5-10 yards. Each participant was instructed to work up to approximately 85-90% of his or her perceived maximal sprint start effort by the last sprint start, and each participant was given as much time as they liked between these practice starts up to a time six-minutes. Furthermore, these sprint starts also gave the primary researcher a chance to remind the participants of proper sprinting deceleration mechanics. This warm-up was followed by a period of six-minutes of active rest in which the participants were encouraged to walk around until it was time to perform the first sprint unresisted, baseline sprint. Although the trials were performed in a random order and each participant would not know which experimental condition they would perform until after their warm-up, the procedures for each condition will be explained in the following order of experimental conditions, (a) the unresisted condition; (b) the 95% condition; and (c) The 110% condition.

The unresisted condition began with the aforementioned warm-up. Following the warm-up session and the six-minutes of active-rest, the participants performed the first timed, 30-meters sprint which was known as the pre-testing sprint of the day. The 30-meters pre-testing sprint, and all timed sprints, were timed throughout the entirety of the sprint as well as at each 10-meter split of each sprint. After the unresisted day pre-test, the participants again observered six-minutes of active-rest. Following the six-minutes of active-rest, the post-testing run for the unresisted day was performed. The pre- and post-testing runs could then be compared for the unresisted trial.

The 95% trial also began with the standard warm-up, followed by the six-minute active-rest period. This active-rest was followed by the pre-testing run which was performed the same way as the pre-testing run of the unresisted condition and, again, this sprint was timed. After the pre-testing run, an active-rest period of six-minutes was given, which was followed by the participants pulling the sled through a distance of 10-meters with a resistance of 35% of the individual’s body mass (in some cases, the sled itself weight equaled slightly more than 35% of a participant’s body mass). What followed the 35% pull was another six-minutes of active-rest. After the active-rest, each participant then pulled the sled with added resistance through a distance of 10-meters with a weight equivalent to 55% of their body mass. Another six-minute period of active-rest follwed the 55% pull. Subsequent to the rest period, each participant performed another pull in which a weight equivalent to 75% of the individual's body mass was pulled through 10-meters. Another six-minutes of active-rest was again observed, followed by one, 30-meters in distance, maximal effort sled-pull with a weight pulled which was equivalent to 95% of each participant's body mass. Following this sled-pull, the participants actively rested for another six-minutes. After this final rest period, the participants performed a 30-meter post-testing sprint. The results of the pre- and post-testing sprints could then be compared. It is important to note that, ideally, the procedures would have only included a pre-testing sprint, followed by one heavy (95%), maximal effort, sled-pull. However, due to the very heavy load pulled, a build-up to the 95% body mass pull seemed to be the safest way to perform this sled-pulling portion of the trial.

The 110% trial, once again, began with the standard warm-up and the subsequent six-minutes of active rest. Following the six-minutes of active-rest, the individuals ran an unresisted pre-testing run for the day. Next, the participants did build-up pulls, again each of these build-up pulls were performed through a distance of 10-meters. Also, like the 95% day, each participant pulled weights equivalent to 35%, 55%, 75%, and 95% of their body mass. All of these pulls (including the 95% pull) were only pulled through 10-meters, with maximal effort, and again, all of these pulls began from each participant's desired three- or four-point sprint start stance. Also like the 95% day, each of these build-up runs were followed by six-minutes of active-rest. After the build-up pulls and the final six-minute active-rest period, the participants performed one 110%-of-body-mass-pull with maximal effort, over a distance of 30-meters. Following this sled-pull, the participants actively rested for six-minutes. Following this rest the participants performed the unresisted, 30-meters, post-testing sprint. The results of the pre- and post-testing results could then be compared. This conclues the description of the testing days and data collection procedures.

Statistical Analysis

Descriptive statistics (mean ± SD) were calculated for all performance variables. A 2X3 factorial MANOVA (time x pulling condition) was used to determine the effect of sled-pulling on sprint performance. Paired samples t-tests with Bonferronni adjustment were used as post hoc analysis when appropriate. The level of significance was set at $p<0.05$ for all inferential statistics.

CHAPTER IV

RESULTS

Descriptive statistics of all performance variables can be found in Table 1. The results of the 2x3 repeated measures MANOVA indicated that there were no significant interactions (F(6,9)=0.31, p=0.92) therefore main effects were analyzed. There was no significant load effect (F(6,9)=1.15, p=0.41) indicating that the loading strategy had no effect on sprint performance. There was a significant time effect (F(3,12)=5.7, p=0.012). The post hoc analysis indicated that the post-testing sprint trial (regardless of loading strategy) was significantly slower than the pre-testing trial for first (F(1)=5.5, p=0.034) and second splits (F(1)=9.4, p=0.008). There was no difference between the pre-testing and post-testing trials for third split (F(1)=0.71, p=0.41).

Table 1

Pre-testing and post-testing split times of each testing condition

	Pre-test (mean times ± sd)			Post-test (mean times ± sd)		
Trial	Split #1	Split #2	Split #3	Split #1	Split #2	Split #3
	0-10m	10-20m	20-30m	0-10m	10-20m	20-30m
0%	2.06 ± 0.13	1.37 ± 0.10	1.30 ± 0.11	2.07 ± 0.14*	1.40 ± 0.11*	1.30 ± 0.13
95%	2.05 ± 0.10	1.36 ± 0.10	1.30 ± 0.12	2.07 ± 0.13*	1.39 ± 0.11*	1.32 ± 0.13
110%	2.06 ± 0.10	1.36 ± 0.13	1.31 ± .17	2.09 ± 0.13*	1.37 ± 0.12*	1.31 ± 0.12

(Note. Listed above are the mean split times ± standard deviation (measured in seconds))

*p < 0.05 in comparison with pre-test means

CHAPTER V

DISCUSSION

The aim of this study was to find out if two different resisted sled-pulling conditions and a third unloaded condition had a post-activation potentiation effect on subsequent 30-meter sprint-running trials of athletes and coaches who regularly implement, and/or are familiar in teaching sprint-running as a means of training.

The statistical analysis revealed that, regardless of the loading strategy, the participants in this study had a slower sprint-running velocity through the first 20-meters between all of the post-testing trials, when compared to the pre-testing trials. Based on time, the findings showed that the differences between pre- and post-testing, through the first 20-meters, were significant. Interestingly, however, although slower from pre- to post-testing, no statistically significant time differences occurred between the third splits of the pre- and post-testing sprints, within each trial.

These findings are quite interesting, and do not match the hypothesis put forth by the researcher that post-testing sprints would be faster than their pre-testing counterparts. Although purely speculative at this point, it would seem logical to assume that two primary factors may be at play which may explain these curious results. One of these factors is fatigue, which may have offset the benefits of the PAP effect (Tillin & Bishop 2009).

Another factor which could have played a part in the outcome of the current study is the possibility of altered kinematics. It has been proposed that heavier than recommended sled-pulling conditions may affect subsequent unloaded sprinting kinematics (Alcaraz et al., 2009; Lockie et al., 2003). Although this carry-over effect of altered kinematics has been proposed by several researchers, very few studies have empirically verified this assertion (Lockie et al., 2003).

These kinematic alterations, if they indeed occurred during the current study, may have been especially prevalent during the drive phase of the sprint runs which followed the heavy sled-pulling sessions. The reason that the drive phase may be the most affected portion of the run probably has to do with a reduction in stride length.

In a study by Alcaraz et al. (2008), a sled-pulling load of 16% of an individual’s body mass, pulled with a shoulder harness, caused a reduction in running velocity of close to 10% (which is currently the approximate maximal speed reduction recommendation to be caused by the implementation of a resisted sprint device). This resistance caused much greater forward trunk lean when compared to the un-resisted condition, as well as a reduction in stride length. It is important to note that the Alcaraz et al. (2008) study, however, only made kinematic measurements during the maximal velocity phase of sprint-running. This means that the Alcaraz et al. (2008), study showed how participants ran during near maximal sprint-running velocity.

Since the current study showed greater discrepancies, between pre- and post-testing times, during the first two splits of the run when compared to the final split, it would seem logical that the greatest kinematic alterations may have occurred at the beginning of the run. However, it cannot be automatically assumed that the altered running kinematics, presumably caused by the effects from sled-pulling, included increased forward trunk lean when compared to the pre-testing conditions. The reasoning for this is because, before the earliest phase of running started, the participants were in a resting, three-, or four-point stance position, whereas, at the start of the last split of the sprint, the participants had already been running for a distance of 20-meters.

It seems possible that during the first few steps of the run, the participants may have run with their shoulders higher than they would have in the pre-testing sprints; probably leaving the torso in a position which was more perpendicular to the ground. This seems like a plausible outcome, especially when one considers the initial resistance that the participants felt was high on the body due to the use of a shoulder harness. This placement of the resistance would seem to pull the participant both upward and backward directions. Furthermore, it would seem logical that, much like the Alcaraz et al. (2008) study, the relatively heavy sled-pulling loads would cause a reduction in stride length.

If the sled-pulling did indeed cause the carry over effects of running with a more upright trunk angle, as well as reduced stride length during the post-testing runs, then it would be probable that, primarily, the horizontal force production during these starts would be less than optimal.

For starters, one might expect that reducing an individual’s optimal stride length could lead to a decrease in force production, especially during the early drive phase of the run. This outcome would seem to reduce the ability to create an optimal impulse during the stance phase of running. Couple this with the thought of running with a more upright running style than would be optimal during this early portion of the drive phase, and what may be observed is that the impulses during the stance phase of each stride would be expressed in such a way that the body could move in a greater vertical direction than would be optimal given the current phase of the sprint. These possible alterations to kinematics coupled with a probable decrease in force production, when comparing post-testing to pre-testing, would probably account for the significantly slower sprint running times at the start of the run.

Also, it should not be overlooked that fatigue, as was mentioned earlier, may have played a role in the slower overall sprint times from pre-to post-testing. The reason for this is fairly obvious, if the participants were experiencing more fatigue during the post-testing sprints, when compared to the pre-testing sprints, then the ability to achieve optimal force production during the drive phase of sprinting would be impaired. If one assumes that fatigue played a role in increasing post-testing sprint times, then a more upright sprint start could result from this possibility. This could result in the participants being unable to achieve the force needed to run with the torso at an optimal angle in relation to the ground during the start. This fatigue factor could also account for the increase in sprint times, from pre- to post-testing, during the final 10-meter spilt of each sprint condition.

It would seem logical, however, that if fatigue played the greatest role in decreasing post-to-testing sprint performance, in relation to the pre-testing sprints, then what would probably be observed is a significant difference in the sprint times of the third split between the pre- and post-testing conditions for each loading strategy. This outcome, however, was not observed, which leads the researcher of the current study to speculate that fatigue may not have played as much of a role as the possibility of reduced stride lengths and the more upright running style at the start, when accounting for increased sprint times which would result in the participants being farther behind where they otherwise would have been by the time they reach the beginning of the third 10-meter split of the sprint.

The reason for believing that fatigue did not play a great role in the resulting post-testing runs is because the PAP effect may have acted to offset the effects that fatigue may have had on the performances of the subsequent post-testing sprints. This would also seem to be a plausible explanation as to why the third split of the sprints, within any of the loading strategies, showed no significant differences for time from pre-to post-testing. To put it simply, if the PAP and fatigue acted, in large part, to offset one another, then one might not expect to observe significant differences between the final splits of the pre- and post-testing sprints within each trial, for both time and kinematics.

These assertions seem logical assuming that PAP and fatigue largely acted to offset one another throughout the entirety of the post-testing runs, while kinematics alterations, from pre- to post-testing, presumably played the greatest role in causing significantly slower sprint starts. This would probably mean that, in order for sprint times of the final splits within each trial to show no statistical difference, the kinematics of the final split of the post-testing sprints must have looked remarkably similar to those of the pre-testing sprints.

It may very well be that the PAP effect occurred during the sled-pulling conditions of the current study even though the performance enhancements were not realized. The possibility of using sled-pulling to acutely enhance subsequent power-dominant athletic performances via the effects of PAP should be researched further in order to find out if there is an optimal way in which to implement sled-pulling so that the performances of power-dominant activities such as sprint-running can be acutely enhanced. Next, some different directions which future research could take sled-pulling with regard to PAP and subsequent sprint-running performance will be explored.

Future Research

A limited amount of research has been conducted which implements sled-pulling as a means of inducing PAP to enhance subsequent sprint-running performances (Smith, 2012; and the current study). This limited amount of research opens the door for several future research ideas regarding sled-pulling as a means of the induction of PAP and subsequent sprint-running performance enhancement.

One area where future research regarding PAP induction via sled-pulling with the hope of enhancing sprint performances is in the area of resistance loads implemented. The only two studies at this point using sled-pulling as a means of inducing PAP are the current study, and the Smith (2012) study. The sled-pulling loads of the current study were 95% and 110% of each participant's body mass, while Smith (2012) implemented sled-pulling resistance loads equaling 10%, 20%, and 30% of each participant's body mass. The resistance loads of the Smith (2012) Study correlated with a reduction in post-testing sprint times, while the resistance loads of the current study resulted in post-testing time increases. It may be that, for most individuals, the loads of the current study are far too heavy because of the amount of fatigue incurred, despite the possibility that this fatigue may have offset the benefits of the PAP effect. This could mean that a possibility for future research could occur with sled-pulling resistances which can be found in gap between 30% and 95%.

This range of sled-pulling resistance loads may be the next logical place to start for future researchers who want to find out if sled-pulling is a viable way to consistently enhance subsequent sprint-running performances, via the acute effects from PAP. However, it may not be as simple as this; it could very well be that rest periods may need to be adjusted as well. Due to the relatively heavy loads of the current study, six-minute rest periods were implemented, during the Smith (2012) study; four-minute rest periods were implemented. Alterations of the rest periods between the implemented resistance loads and the subsequent unresisted sprint-run could prove to be a difference maker for the unresisted sprinting performances which follow the sled-pull. This could mean that as the loads become greater within the 30-95% resistance range, rest periods will have to become greater as well.

Although looking at varying resistance loads and varying rest times may be a good place to begin future research studies, these factors only take into account the amount of resistance and amount of rest in relation to an individual’s body mass (due to the fact that the loading is based on body mass alone). This leads to another area where future sled-pulling research could be taken.

The thought that current loading strategies for sled-pulling rely solely on body mass may not be the best measure of how heavy an individual should be loaded. It could be that a better measure of how heavy an individual should be loaded when using sled-pulling to enhance sprint-training, should be based on some sort of strength measure such as how much an individual can back- or front-squat, deadlift, or power-clean, in relation to their own body weight. It could be that if one individual can lift more weight than another individual, relative to bodyweight, them it may be that this relatively stronger individual can be loaded, during a sled-pull, heavier than a person who can lift relatively less weight, without experiencing detrimental effects to subsequent sprint-runs.

It could be that a measure other than body mass alone should be the measure used to determine the resistance loads implemented in future sled-pulling, or other resisted sprint training, research. This is yet another area of research for future sled-pulling studies as a means of enhancing sprint-running performances.

The possible directions in which to take future research do not end with the aforementioned possibilities, however. It could very well be that the longitudinal use of sled-pulling may be the most effective way to consistently observe the acute effects of PAP which can acutely enhance sprint-running. On the surface, this may sound like a confusing idea, but really it is quite simple. It could be that sled-pulling could be studied over several weeks or months (longitudinally) where, over time, the resistance is continually added, giving an individual time to adapt to pulling heavier and heavier weight as part of their sprint training. This may allow for morphological changes to occur in muscles used primarily in creating the impulse in every step (sometimes known as the triple extensors). This longitudinal training style may also cause neurological adaptations that allow greater amounts of muscle tissue to be recruited. Several weeks or months of overloaded sprint-training via sled-pulling would also allow an individual to be adapted to that kind of training which may reduce their likeliness of being fatigued from such an activity.

When using the longitudinal resisted sprint training method of sled-pulling, the individuals could continue to increase the load as they adapt. Prior to implementing the sled-pulls, the participants could time their sprints which follow a warm-up, which could be known as the pre-testing sprints. Following the sled-pulls, there could be timed sprints of the same distance as the pre-testing sprints, and these would be known as the post-testing sprints. The pre- and post-testing sprints could then be compared and over time, the effects of the different loads could be compared. It might be found that each individual has a different maximal resistance which could be pulled in order to achieve the optimal sprint-running performance via PAP induced by sled-pulling. This long term use and familiarization may allow an individual to consistently pull a given resistance load a certain amount of time before a sprint-running performance in order to reduce their sprint running performance times by a certain percentage or measure of time.

Another area of future research in regards to sled-pulling has to do with kinematic effects. The carry-over effects of sprint-training with sled-pulling loads which are in excess of currently recommended resistance loads should be evaluated through future research. The question still remains; do heavier than recommended resistance sled-pulling loads have an effect on subsequent, unresisted, sprint-running kinematics? Furthermore, if heavier than normal sled-pulling loads indeed do affect subsequent, unresisted, sprint-running kinematics, then are these effects detrimental or helpful to the subsequent sprinting performance? The answers to these questions should probably be answered in relation to both short-term and longitudinally implemented sled-pulling studies.

It is clear to see that there are multitudes of ways in which future researchers can study sled-pulling and its effects on sprint-training via PAP.

Conclusion

In conclusion, sled-pulling is a commonly implemented tool in sprint-training for a variety of reasons. Although guidelines currently exist for ways in which resisted sprint-training such as sled-pulling should be implemented, it should be recognized that these guidelines are not conclusive. The results of the current study showed that very heavy sled-pulls resulted in slower relative running times than unresisted sprinting alone. However, as was explored earlier, it may be that PAP was induced and possibly the effects from the PAP could have been offset by the fatigue incurred due to the very heavy relative resistance loads.

Since sled-pulling is such a commonly used sprint-training method, and since many sleds themselves are actually heavier than the recommended resistance loads, it would seem to be a good idea that future research takes into account many factors when studying sled-pulling especially in relation to the possibility of acute enhancements which may come through the induction of PAP. Studies for the future may include, (a) how does the relative strength of an individual effect resistance loads?, (b) how do varying resistance loads effect the rest time needed before a subsequent sprint should be performed?, (c) how does the longitudinal use of sled-pulling effect kinematics? (d) how does the longitudinal use of sled-pulling effect the reliability of using sled pulling as method to acutely enhance sprinting performances? All of these questions could be the focus of future research in order to more accurately know how sled-pulling may acutely effect subsequent sprint-running performances.

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APPENDIX A

UNIVERSITY OF NORTHERN IOWA

HUMAN PARTICIPANTS REVIEW
INFORMED CONSENT
(Sample for Adult Participants – Use Second Person Language Except for Agreement Statement)

Project Title: The Acute Effects Of Multiple resisted Sled-pull Loads On Subsequent Sprint-Running Perfomances

Name of Investigator(s): _Carl Crouse________________________________

Invitation to Participate: You are invited to participate in a research project conducted through the University of Northern Iowa. The University requires that you give your signed agreement to participate in this project. The following information is provided to help you made an informed decision about whether or not to participate.

Nature and Purpose: The purpose of this study is to determine if running resisted sprints at various resistance loads (via sled-towing) has the ability to enhance subsequent uresisted sprint-running trials.

Explanation of Procedures: During this study, the participants will take part in three testing sessions. Each of the three testing sessions will include: (1) A standardized, supervised, dynamic warm-up, (2) an unresisted, timed and video recorded, all-out sprint-run, (3) a resisted run (sled-towing) to potentially induce post-activation potentiation and (4) a post-test, unresisted, sprint-run. Each participant will take 5 minutes rest between each of the four parts of each of the three sessions.
Describe all procedures to be followed, including their purpose(s), duration, frequency, use of any audio or video recording, what will happen to the data/information at the end of the study. Include enough detail that the participant has a reasonable idea of what he/she will be doing and what they will be asked about. State any anticipated circumstances where the participant's participation may end without regard to the participant's consent.

Discomfort and Risks: Describe any physical, psychological, social, legal, and/or economic risk(s) or cost(s) resulting from the project. If there are no more than minimal risks--discomfort, burden, inconvenience--this should be so stated. This may be stated in one of several ways: Risks to participation are minimal. Risks to participation are similar to those experienced in day-to-day life. There are no foreseeable risks to participation.

Benefits and Compensation: Describe any direct benefit(s) that may result from the study. Benefits would include improved physical or mental health (e.g., from treatment), improved skills, etc. Compensation is distinct from benefit and would include cash, gifts, or academic credit provided for the person's time or travel expenses. If the individual participant will receive no direct benefit, this should be stated. If applicable, describe how voluntary or involuntary withdrawal or termination affects benefits. Note that compensation should be equivalent across participant groups and cannot be used to coerce participation. That is, if compensation for time is provided, then a portion of the compensation must be provided (pro-rated) even if the person terminates their involvement prior to completing the study.

Confidentiality: State the way the participant's confidentiality will be maintained: persons or organizations to whom information from the study will be furnished, nature of the information furnished, purpose of the disclosure. For example: "Information obtained during this study which could identify you will be kept confidential. The summarized findings with no identifying information may be published in an academic journal or presented at a scholarly conference".

Right to Refuse or Withdraw: Provide information about the voluntary nature of participation and the ability of the participant to stop at any time without penalty. For example: “Your participation is completely voluntary. You are free to withdraw from participation at any time or to choose not to participate at all, and by doing so, you will not be penalized or lose benefits to which you are otherwise entitled.”

Questions: Participants should be able to seek additional information about the project. For example: “If you have questions about the study you may contact or desire information in the future regarding your participation or the study generally, you can contact Carl Crouse at 319-415-9916 or (if appropriate) the project investigator’s faculty advisor Dr. Robin Lund at the Department of Health Physical Education and Leisure Services, University of Northern Iowa 319-273-3615. you can also contact the office of the IRB Administrator, University of Northern Iowa, at 319-273-6148, for answers to questions about rights of research participants and the participant review process.”

Agreement: Include the following statement:

> **I am fully aware of the nature and extent of my participation in this project as stated above and the possible risks arising from it. I hereby agree to participate in this project. I acknowledge that I have received a copy of this consent statement. I am 18 years of age or older.**

______________________________ ________________
(Signature of participant) (Date)

____
(Printed name of participant)

______________________________ ________________
(Signature of investigator) (Date)

______________________________ ________________
(Signature of instructor/advisor) (Date)

[NOTE THAT ONE COPY OF THE ENTIRE CONSENT DOCUMENT (NOT JUST THE AGREEMENT STATEMENT) MUST BE RETURNED TO THE PI AND ANOTHER PROVIDED TO THE PARTICIPANT. SIGNED CONSENT FORMS MUST BE MAINTAINED FOR INSPECTION FOR AT LEAST 3 YEARS]

APPENDIX B

PHYSICIAN'S SCALE

APPENDIX C

SLED

APPENDIX D

SLED SET-UP WITH TETHER AND HARNESS

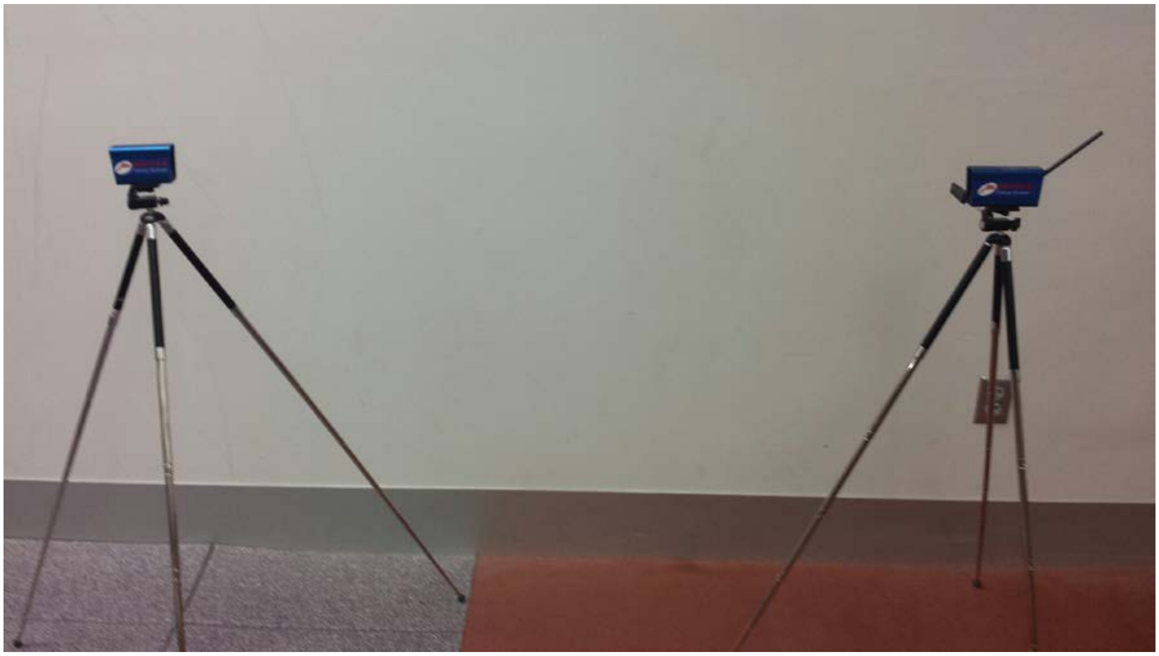
APPENDIX E

BROWER TIMING SYSTEM

APPENDIX F

BROWER ELECTRONIC TIMING GATE

(3 GATES IN TOTAL)



APPENDIX G

BROWER THUMB PAD

(LIFTING HAND OFF OF PAD STARTED THE TIMING)

APPENDIX H

WEIGHT PLATES PUT ON SLED FOR ADDED RESISTANCE