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Effect of a High-Intensity Isometric Potentiating Warm-Up on Bat Velocity

By

Sheryl Gilmore

Accepted in Partial Completion
of the Requirements for the Degree
Master of Science

Kathleen L. Kitto, Dean of the Graduate School

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MASTER'S THESIS

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Date: July 24, 2013
Effect of a High-Intensity Isometric Potentiating Warm-Up on Bat Velocity

A Thesis
Presented to
The Faculty of
Western Washington University

Accepted in Partial Completion
of the Requirements for the Degree
Master of Science

Sheryl L. Gilmore
July, 2013
Abstract

The purpose of this study was to examine the acute effect of a high-intensity isometric potentiating warm-up on subsequent maximal horizontal bat velocity in experienced female softball players (n = 28). The isometric potentiating warm-up consisted of 3 sets of 5-second maximal voluntary contractions held in the early swing phase, pulling against an immovable device. The warm-up was designed to acutely enhance muscle performance by inducing post-activation potentiation (PAP), ultimately eliciting an increase in bat velocity. Because optimal recovery duration following a potentiating warm-up can be highly variable, swing trials were conducted at pre-determined rest intervals (1, 2, 4, 6, 8, 10, and 12 minutes) to identify the recovery time which may have allowed for maximal possible benefits. Bat velocity was measured immediately prior to bat-ball impact. The results indicate that the phase specific isometric warm-up elicited increased bat velocity at 2, 4, 6, 8, 10, and 12 minutes. Statistical analysis was carried out using a one-way repeated measures analysis of variance (ANOVA) and showed that maximal horizontal bat velocity was significantly enhanced 6 minutes following the isometric warm-up protocol (+1.27 m/s, +2.84 mph, +4.93%; p < 0.05). Additionally, a significant quadratic trend was observed, with bat velocity peaking at six minutes and subsequently decreasing (p < 0.05). No correlation was found between baseline measures of absolute (ABS) and relative (REL) strength and the amount of potentiation that occurred. The positive effect of the potentiating warm-up protocol is similar to what has been reported in the literature regarding PAP and explosive performance.
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Keywords: post-activation potentiation (PAP); bat velocity; isometric warm-up.
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Chapter I
The Problem and Its Scope

Introduction

While the sport of fastpitch softball has dramatically increased in popularity over the last twenty-five years, the body of research pertaining to the scientific principles and training modalities specific to this sport is inadequate. Skills demonstrated by softball players comprise complex whole-body movements that must be mastered in order for success in the sport. Batting, in particular, is a difficult skill, as pitched softballs can reach speeds up to seventy-miles-per-hour (31 meters per second) from a distance of forty-three feet away; forcing the batter to both decide to swing and execute the swing in less than 0.41 seconds. In order to be a successful hitter, the player must possess proper swing mechanics and the ability to optimize explosive rotational force production in a short amount of time (Szymanski, DeRenne, & Spaniol, 2009). Bat velocity depends on the coordination of sequential, rotational, explosive movement (Welch, Banks, Cook & Draovitch, 1995). Because bat velocity must be produced through the whole-body so quickly, improving bat velocity is of particular importance for offensive success in softball players. Although the research specifically regarding softball is insufficient, many baseball warm-up protocols and training programs focus on improving strength, power, and ultimately, bat speed (Flyger, Button, & Rishiraj, 2006). As college softball hitters actually have less time to react to a pitched ball than many professional baseball players, any exercise or warm-up activity which leads to increased bat velocity in female softball players may have positive implications.
Post-activation potentiation (PAP) has recently become a progressively popular method to increase power performance. PAP is the enhancement of muscle function following a high force activity. After a short bout of high-intensity exercise, or a pre-load stimulus, the muscles involved are both fatigued and potentiated (Rassier & MacIntosh, 2000). The subsequent performance of the muscles is dependent on the interaction of these two factors. While well-designed research studies consistently show that this type of warm-up and training may improve rate of force development (RFD) and increase power performance (Tillin & Bishop, 2009), there continues to be controversy surrounding this phenomenon due to limitations in the research.

Products, commonly seen in the baseball and softball realm, have been developed, with the goal of acutely increasing bat velocity. PAP supports the notion of alternating heavy and light resistances to increase power output (Hodgson, Docherty, & Robbins, 2005). As one of the simplest methods of employing this idea, weighted implements are often added to baseball and softball bats during a pre-batting warm-up routine in order to optimize at-bat bat velocity (Reyes & Dolny, 2009). Though a perceived increase in bat speed exists after a weighted bat warm-up, multiple studies show that using weighted bats elicits no significant difference in bat speed production in both baseball and softball players (Reyes & Dolny, 2009; Szymanski, et al., 2011; Szymanski, et al., 2012). In other research, a decrement in bat speed has been found after using weighted bats (DeRenne, Ho, Hetzler, & Chai, 1992; Southard & Groomer, 2003). These negative results may be due to the dynamic nature of the high force activity adversely altering the mechanics of the
swing (Nakamoto, Ishii, Ikudome, & Ohta, 2012; Southard & Groomer, 2003). New research, though, has indicated that high-intensity isometric muscle actions can evoke a greater muscle PAP than dynamic conditions (Rixon, Lamont, & Bemben, 2007).

Although its mechanisms may still be debated and there are several variables which can interfere with its performance effects, PAP, under proper conditions, can elicit an increase in power output (Chiu, Fry, Weiss, Schilling, Brown, & Smith, 2003; Kilduff, et al., 2007; Rixon, Lamont, & Bemben, 2007) and one’s ability to produce force more rapidly (Gilbert & Lees, 2005; Gullich & Schmidtbleicher, 1996). Considering that the ability to generate and transfer force through the body as quickly as possible is one of the most important factors in the effective execution of the swing (Szymanski, DeRenne, & Spaniol, 2009), possibility exists in using an isometric conditioning contraction as a pre-batting potentiating warm-up protocol. If successful, an increase in bat velocity may be observed.

**Purpose of the study**

The purpose of this study was to determine the acute effect of a high-intensity isometric potentiating warm-up on subsequent maximal bat velocity in experienced female softball players. Research indicates that PAP is primarily exhibited in well trained individuals (Baker, 2003; Chatzopoulos, et al., 2007; Kilduff, et al., 2007; Weber, Brown, Coburn, & Zinder, 2008; Young, Jenner, & Griffiths, 1998) and that absolute strength is correlated to the percent performance enhancement (Kilduff, et al., 2007). Therefore, strength testing was analyzed in
conjunction with bat velocity. As optimal recovery duration can be highly variable (Gullich & Schmidtbleicher, 1996; Jensen & Ebben, 2003; Kilduff, et al., 2007; Wilson, et al., 2012), trials were conducted at pre-determined rest intervals in order to identify the recovery time which allowed for maximal possible benefits.

**Hypothesis**

The experimental hypothesis states that the potentiating warm-up utilizing high-intensity isometric contractions will elicit a significant increase in bat velocity when compared to subjects’ established baseline bat velocity.

**Significance of the study**

Bat velocity has been deemed crucial for success in hitting. There is very little time for the perceptual decision making process, using information about the flight of the pitch to organize the swing motion (Katsumata, 2007). Because of the time needed to judge a pitch, it is favorable for the hitter to wait until the last possible moment before initiating motion towards the ball, rather than attempt to react to the pitch mid-swing (Katsumata, 2007). A decreased swing time, or higher bat velocity, provides the hitter more time to observe the oncoming pitch, allowing for a more accurate evaluation of the speed, location, and movement of the pitch, increasing the hitter’s chances of making solid contact with the ball (Reyes, Dickin, Dolny, & Crusat, 2010). In this regard, bat velocity is even more important to offensive success in softball players, when compared to baseball players. In softball, pitches not only travel in a high to low trajectory, as they do in baseball, but they also travel in a low to high trajectory with underhand rise-balls. In addition, the positive relationship between bat velocity and the distance the ball travels after
impact has been well-established (Reyes, Dickin, Dolny, & Crusat, 2010). Greater bat velocity facilitates an increase in batted ball velocity and distance, increasing the chances of successful at bats (Szymanski, McIntyre, Szymanski, Bradford, Schade, Madsen, & Pascoe, 2007a).

The decreased response time in softball hitting combined with the reported lower bat velocities in softball hitters, when compared to baseball hitters (Flyger, Button, & Rishiraj, 2006), shows the need for a warm-up device that can increase bat velocity in softball players. Such a device could improve the athlete’s offensive performance and give coaches another medium with which they could prepare their athletes for competition.

Furthermore, softball provides a unique setting in which to utilize the PAP phenomenon. Unlike most other team sports, the timing of individual offensive performance is fairly predictable due to having an established batting order. The development of a successful pre-batting warm-up protocol would have important implications in the sport, as well as provide evidence for the PAP phenomenon.

Limitations of the Study

- Hitting a softball in a game situation is an open skill, however this test for horizontal bat velocity was conducted as a closed skill, as the batter hit the ball off of a batting tee. The dissimilarity between the testing environment and an actual game situation was a limitation of this study.
- The continuous testing of the potentiated activity, or bat velocity during the swing, can affect the subsequent potentiated activities. As
there will be several attempts at finding optimal duration for potentiation after the potentiation protocol, fatigue may last longer than it normally would without frequent interruptions by intermittent testing.

- Although subjects were selected from a variety of different teams around western Washington, selection bias still exists. All of the softball players selected were competitive athletes and wanted to increase their bat velocity.

- The differences in swing mechanics between subjects can impact the kinematic chain and different muscles’ contributions to bat velocity.

- Subjects have played softball for at least five years and currently participate in a softball program which trains year-round. These results may not be applicable to the general public and recreational athletes.

- Workloads and muscle activation patterns can vary between subjects. Subjects did receive clear and like instructions on the proper use of the warm-up device, but the intensity of an isometric contraction can be difficult to control.

**Definition of Terms**

| Bat Handle: | The end of the bat which the hitter holds hand over hand. The grip, just above the knob of the bat (Gibbens, Kaiser, & Youngblood, 2010). |
| **Bat Head:** | The end of the bat that is used to make contact with the ball, also called the barrel of the bat. This portion contains the “sweet spot,” or the center of percussion (see below), of the bat and represents where the hitter should ideally make contact with the ball. (Veroni & Brazier, 2006). |
| **Bat Velocity:** | The maximal speed of bat coming through the strike zone, measured during a swing (Szymanski, DeRenne, & Spaniol, 2009). |
| **Center of Percussion** | Also known as the “sweet spot” of the bat, this is the region, approximately five to seven inches from the end of the barrel, where maximum batted-ball speed is produced and the vibrational sensation in the batter’s hands is minimized (Gibbens, Kaiser, & Youngblood, 2010). |
| **Clockwise and counterclockwise movements in hitting (for right handed hitter):** | Clockwise movements during hitting are movements made opposite the intended direction (counter-rotational-movements) and often take place in the coiling phase. Counterclockwise movements made in hitting are the rotational movements forward towards the ball (the intended direction) made during the swing (Welch, Banks, Cook & Draovitch, 1995). |
| **Coiling Phase:** | The clockwise countermovement action (discussed above) of the upper extremity and torso. Coiling occurs during the swing to preserve the stretch reflex and generate peak power to the ball (Welch, Banks, Cook & Draovitch, 1995). |
| Term                          | Definition                                                                 |
|-------------------------------|---------------------------------------------------------------------------|
| Dry Swings                    | Practiced swings which do not involve making contact with a ball (Szymanski, et al., 2011). |
| Dynamic muscle action:        | Action that produces movement of the skeletal system (Neumann, 2010).       |
| Eccentric Muscle Action:      | Elongation of muscle while under tension due to an opposing force being greater than the force generated by the muscle (Neumann, 2010). |
| Isometric Muscle Action:      | Activation of a muscle or muscle group(s) which generates force without producing movement of the skeletal system (Neumann, 2010). |
| Kinetic Link                  | The patterns and contributions of individual body segments which contribute to a whole-body dynamic movement. Passing momentum from large base segments to smaller adjacent segments (e.g. the transfer of force from the hips to the torso, and from the torso to the arms during the swing) (Welch, Banks, Cook & Draovitch, 1995; Szymanski, Szymanski, Bradford, Schade & Pascoe, 2007b). |
| Muscular Power                | The ability of a muscle or group to rapidly perform work (Neumann, 2010).   |
| Muscular Strength:            | The ability of a muscle or group to exert force. Relative strength refers to strength per kilogram body weight, while absolute strength refers to muscular strength not related to body weight (Neumann, 2010). |
| **On Deck Batter:** | “On deck” refers to being next to bat in the line-up during a baseball or softball game. The player who is on deck traditionally waits in a location in foul territory called the on deck circle where the player can warm-up prior to their at-bat (Veroni & Brazier, 2006). |
| **Post-activation Potentiation (PAP):** | The phenomenon whereby muscular performance is enhanced acutely due to a previous activity that is executed at a relatively high intensity (Tillin & Bishop, 2009). |
| **Potentiating Activity:** | The activity causing the enhanced muscle function (Tillin & Bishop, 2009). |
| **Potentiated Activity:** | The activity performed after the potentiating activity, through which muscle function is augmented. Also known as a conditioning contraction (Tillin & Bishop, 2009). |
| **Rate of Force Development (RFD):** | A measure of the rate at which a force is developed. RFD determines the force that can be generated in the early phase of muscle contraction (0–200 milliseconds) (Aagaard, Simonsen, Andersen, Magnusson, & Poulsen, 2002). |
| **Repetition Maximum (RM):** | The greatest weight moved at a predetermined number of repetitions (Baechle & Earle, 2008). |
| **Slot Position:** | A position reached during the early to middle phase of the swing. Slot position is thought to be a critical point in the swing for muscle activation and the efficient transfer of force (Shaffer, Jobe, Pink, & Perry, 1993). |
| Stance: | The hitter’s set-up in the batter’s box prior to pitch delivery (Veroni & Brazier, 2006). |
|---------|-----------------------------------------------------------------------------------|
| Stride: | When the hitter takes a step towards the pitcher during the delivery of the ball. Is measured by the distance traveled by the front foot during the single support phase of the swing (stance to foot down or block) and varies between hitters. It is often used as a timing mechanism for the hitter in order to make optimal contact with the ball and helps achieve a powerful position to start the swing (Veroni & Brazier, 2006; Welch, Banks, Cook & Draovitch, 1995). |
| Swing:  | The acceleration phase marked from the coiling phase to the snap of the bat through the strike zone. The end of the swing is characterized by deceleration of the body segments and bat following its angular path (Shaffer, Jobe, Pink, & Perry, 1993; Welch, Banks, Cook & Draovitch, 1995). |
| Twitch Potentiation (TP): | The short-lived increase in twitch force amplitude following a maximal tetanic muscle contraction (Moore & Stull, 1984). |
Chapter II

Review of Literature

Introduction

Much of the research synthesized in this literature summary involves studying baseball swing kinematics, as little research exists solely on the kinematics of the softball swing. However, a softball swing does not greatly differ from a baseball swing, as they involve the same muscle groups and share similar movement patterns. This chapter will also focus on literature regarding current warm-up devices used with the aim of increasing at-bat bat velocity. Furthermore, a comprehensive review of the current literature on post-activation potentiation is included. This section discusses the possible underlying mechanisms of PAP, as well as the many variables influencing this phenomenon. Also, prospective methods of inducing potentiation are discussed in detail, as well as the measurements associated with PAP and bat velocity.

The Swing

Like other body motions in softball, the dynamic phases of the swing show a sequential, proximal-to-distal energy transfer (Flyger, Button, & Rishiraj, 2006) and can be broken down into separate parts that include both linear and rotational movements (Welch, Banks, Cook & Draovitch, 1995). As the phases of the swing have been divided via a variety of different methods by researchers, coaches, and players, there has not been one uniform way of discussing the phases of hitting in the literature. While swing mechanics differ from player to player, the general set-
up, stance, and dynamic swing pattern will be discussed for a right-handed hitter (right side of the body faces the catcher, left side of the body faces the pitcher).

**Set-up and stance.** The hitter loosely grips the bat with both hands so that their proximal interphalangeal joints are aligned, right hand over the left. While holding this grip, both the right and the left arms are in flexion as the bat rests on the anterior aspect of the right deltoid; in this position the forearms should form an inverted “V” shape (Veroni & Brazier, 2006). The hitter's stance can vary, but usually the feet are positioned just wider than hip width apart with the toes typically pointed straight out in front of the hitter (Flyger, Button, & Rishiraj, 2006). A stance that is too wide may inhibit subsequent weight transfer and hip rotation during the swing, and a stance that is too narrow may produce a long stride, unnecessary head movement, and poor ball tracking (Veroni & Brazier, 2006). Hitters may alter the alignment of their feet depending on style, preference, pitch placement, or favorable ball placement in the field. Hitters may move the front (left) foot further away from the plate than the right foot for an open stance, or closer to the plate for a closed stance (Flyger, Button, & Rishiraj, 2006). The hitter maintains an athletic stance with knees flexed, heels lifted slightly off the ground, and weight on the metatarsophalangeal joints (balls of the feet) (Veroni & Brazier, 2006). While in this position, the torso is bent slightly forward, towards home plate (Veroni & Brazier, 2006). The whole-body center of mass is shifted slightly towards the back (right) foot. The head of the hitter is rotated counterclockwise (to the left) so that the eyes are looking over the left shoulder towards the pitcher in anticipation for the delivery of the ball.
Coiling phase (load / trigger). The swing is initiated with a weight shift toward the back (right) leg (Welch, et al., 1995). Simultaneously, the upper body rotates clockwise around the axis of the trunk, initiated by the arms and shoulders, and followed closely by the hips (Welch, et al., 1995). This countermovement (moving opposite the intended direction) marks the beginning of the coiling process and has been referred to as the “load” or “trigger” (Welch, et al., 1995). Coiling generates a stretch and stores elastic energy in the torso that is released during the swing.

Push / foot-off / stride. Immediately following the smooth initiation of coiling, the front (left) leg breaks contact with the ground (foot off) during the pitcher’s delivery of the ball and moves towards the pitcher. This phase of the swing establishes timing and helps the hitter achieve a powerful position to start the swing (Veroni & Brazier, 2006). The stride is considered to be a single support phase and occurs by flexion of the left hip, elevating the thigh and flexed knee. Before returning to double-support, counter-torques are created as the torso, shoulders, and arms continue to move in a clockwise fashion while the hips begin to accelerate towards the ball in a counter-clockwise direction (Welch, et al., 1995). Katsumata (2007) measured ground reaction forces during all phases of the swing and established that the back-to-front (back foot to front foot) weight transfer during this phase is crucial to producing maximal bat speed and that the shear force applied by the back (right) foot drives the hitter in a linear direction toward the ball. Reyes and colleagues (2010) clearly show the significant relationship between powerful lower bodies and higher generated bat velocities.
**Foot contact / block.** As the hitter’s stride foot makes contact with the ground, the “closed chain energy transfer” is initiated and the linear component and the rotational component begin to interact with each other (Welch, et al., 1995). At foot down, the weight is transferred to the firm front leg and the center of pressure moves ahead of the center of mass (Veroni & Brazier, 2006; Welch, et al., 1995). The application of shear force by the left foot represents the “blocking” of the linear motion which, according to the kinetic link theory (discussed later), creates a rotational motion at the hip segment, facilitating its counterclockwise acceleration around the axis of the trunk. As the hips rotate, the back (right) thigh internally rotates, the right knee remains flexed, the right foot pivots, the heel lifts off the ground, and the hands accelerate towards the ball (Veroni & Brazier, 2006). The flexed right elbow turns in the counterclockwise direction simultaneously with the flexed right knee. This is known as “slot position” and it is thought to be a critical point in the swing for muscle activation and the efficient transfer of force (Shaffer, Jobe, Pink, & Perry, 1993).

Slot position occurs between blocking and extension, during the early to middle phase of the swing. As the bat moves towards ball contact, the hitter’s hands should take the knob, or most proximal part, of the bat directly towards the inside path of the ball, pushing the hands ahead of the barrel of the bat, creating “bat lag”. Bat lag is an advantageous momentary component of a successful swing occurring between slot position and ball contact (Welch, Banks, Cook, & Draovitch, 1995). If the forearms go into extension early, rather than stay flexed at the elbow, the hands cast outwards away from the body, increasing the moment of inertia, and slot
position is not reached. Early extension leads to a long swing, a decrement in bat velocity, loss of bat control, and decreased force transferred to the ball (Veroni & Brazier, 2006).

**Extension / ball contact.** As contact nears, the front (left) knee goes into complete extension to resist forward translation of the center of mass (Veroni & Brazier, 2006). The right knee remains flexed and both legs undergo deceleration prior to ball contact, providing a stable base of support for the rotation of the upper extremities (Veroni & Brazier, 2006; Welch, et al., 1995). The shoulders, arms, and hands rotate around the trunk towards the ball. At ball contact, the body uses coordination and position to generate bat speed and direction (Welch, et al., 1995).

During a biomechanical analysis of professional baseball players swings, Welch and colleagues (1995) showed that the trunk moves through a substantial range of motion in an effort to assist in bat position and become an extension of the front leg’s blocking action. In both arms, humeral and forearm extension occurs allowing the bat to snap through the strike zone and make forceful contact with the ball (Veroni & Brazier, 2006). At contact, the bat head may either be level with the handle, below the handle, or, due to the motion of a softball pitcher’s arm propelling the ball from the hip, upwards, the bat head may be positioned slightly above the hands in order to increase the amount of time that the bat and ball are in the same plane. The position of the bat head relative to the bat handle should match the position of the right shoulder relative to the position of the left shoulder (Veroni & Brazier, 2006). For example, if the bat head is below the bat handle, creating an
upper-cut type swing often seen in power hitters, the right shoulder should be lower at contact than the left shoulder.

**Finish.** Upon release of the ball from the bat, the arms and wrists are fully extended as the arms, forearms, and wrists form a straight line with the bat. The hitter should swing through the ball so that the bat head continues toward center field until full extension is accomplished (Veroni & Brazier, 2006). Over the course of the swing the eyes should follow the path of the ball as the head remains still. With the finish of the swing, no matter the outcome, the head should briefly remain looking at the contact point and the hands should finish around the body following their angular path to the ball (Veroni & Brazier, 2006). The hitter’s body should be stacked so that the back (right) shoulder is over the back (right) hip, and the hip is over the back (right) knee (Veroni & Brazier, 2006).

**Muscles involved.** There are few known electromyography (EMG) studies analyzing muscle activity during a baseball swing and none examining a softball swing. Shaffer and colleagues (1993) have provided the most comprehensive and quantitative assessment of muscle activity during the swing. This study analyzed the pattern of muscle activity during the swing of eighteen professional baseball players. Fine wire electrodes were placed into the supraspinatus, triceps (long head), posterior deltoid, and middle serratus anterior of each subject’s lead arm (arm facing the pitcher), as well as the lower gluteus maximus of their back leg (leg facing the catcher). Surface EMG was used to analyze the right and left erector spinae, abdominal obliques, and the vastus medialis, as well as the semimembranosus and the biceps femoris of the back leg. Resting and maximum
muscle test (MMT) recordings were made for each muscle. After an adequate warm up, all subjects hit six fastballs while a high-speed camera captured each swing along with synchronized EMG data. The researchers then divided the swing into four phases: “windup”, “pre-swing”, “swing” (later classified as early swing, middle swing, and late swing), and “follow-through”.

Shaffer and colleagues (1993) found a distinct pattern of muscle activation during the swing. The lower extremity muscles seem to be crucial in early pelvic stabilization and to the generation of power. The hamstrings are responsible for both hip stabilization and the drive provided to initiate swing and the forceful rotation of the hips toward the ball, uncoiling the torso. Vastus medialis activity increased throughout the swing contributing to the forward thrust of the hips and torso. The erector spinae and abdominal oblique muscles showed high levels of activation during the swing, allowing for stabilization of the trunk and smooth and efficient rotation and force transfer. The activity of both the posterior deltoid and triceps was highest in the pre and early phases of the swing and was important in positioning for successful ball contact. In sum, the trailing leg muscles (semimembranosus, biceps femoris, gluteus maximus, and vastus medialis), trunk muscles (bilateral erector spinae and abdominal obliques), and lead arm muscles (posterior deltoid and triceps) proved to be most active during the pre-swing phase and the early swing phase, as the hitter approaches the “slot position” (Shaffer, Jobe, Pink, & Perry, 1993). Therefore, the pre-swing phase and early phase of the swing seem to represent the critical period for force production.
Kinetic link. It is clear through this kinematic analysis of the softball swing that the body is manipulated in order to transfer the greatest amount of velocity to the ball. The closed chain nature of the swing and the sequential motions of body segments allow for power to move through a kinetic chain link (Welch, et al., 1995). The previously mentioned study by Shaffer and colleagues (1993) clearly shows that skilled batting relies on the coordinated transfer of energy from the lower limbs to the trunk, and finally to the upper limbs. When the feet are in contact with the ground, rotational forces are initiated through the larger and stronger muscles in the lower-body and are then transferred through the smaller muscles of the upper-body to facilitate maximal velocity towards the ball (Reyes, et al., 2010). This efficient energy transfer from the lower- to the upper-body is especially important to female softball players, as females generally have weaker upper-body musculature, when compared to males. The countermovement at the beginning of the softball swing stretches the torso eccentrically and, upon the initiation of the forward movement towards the ball, the muscle action at the shoulders, arms, and wrists is enhanced by the energy transfer from the torso and lower extremity. The largest body segments in the chain are the first to rotate, followed by the smaller segments: hips, torso, shoulders, arms, wrists, and bat (Reyes, et al., 2010). In order to transfer the forces generated by the lower body to the upper body, the hitter must possess adequate levels of torso rotational strength (Szymanski, et al., 2007a). Since bat velocity represents the summation of the individual segment velocities involved in the swing (Reyes, et al., 2010), it makes sense that the rate of force development (RFD) and power of the active musculature can greatly affect resulting
bat velocity. Coaches and players have come up with many ways to prepare the muscles for the swing in attempt to increase the power generated in the body in order to be transferred to the ball.

**Current warm-up devices used to increase bat velocity.**

A variety of warm-up devices are available to baseball and softball players for use prior to their at-bat. Players often swing heavier bats, multiple bats, weighted donuts or other weighted implements and resistive devices during their warm-up routine in attempt to achieve greater at-bat bat velocity. Though it is common to see batters, many of which are professional athletes, in the on-deck circle warming up by swinging a weighted implement, the advantage of such activity has been disputed in the scientific literature.

Some researchers have reported no significant difference in bat velocity after warming-up with a variety of different devices, including weighted donuts and heavy bats, (Bassett, et al., 2011; Reyes & Dolny, 2009; Szymanski, et al., 2011; Szymanski, et al., 2012; Wilson, et al., 2012), while others have reported that weighted warm-up implements cause a decrease in bat velocity (Derenne, Ho, Hetzler, & Chai, 1992; Montoya, Brown, Coburn, & Zinder, 2009, Otsuji, Abe, & Kinoshita, 2002; Southard & Groomer, 2003). In multiple studies, however, hitters reported greater perceived bat velocity after warming up with a weighted device, while results indicated that their bat velocity actually decreased by an average of 3.3% from their pre-weighted swings (Nakamoto, Ishii, Ikudome, & Ohta, 2012; Otsuji, Abe, & Kinoshita, 2002). These results indicate that weighted bats do not produce greater bat velocity, but do provide a "kinesthetic illusion" or feeling of
greater velocity; suggesting that the benefit of a weighted bat warm-up may be psychological and not biomechanical (Nakamoto, Ishii, Ikudome, & Ohta, 2012). In addition, this illusion of increased bat velocity, coupled with an actual reduction in bat velocity, may interfere with appropriate timing during the swing.

DeRenne and colleagues (1992) published one of the earliest studies examining the effects of warming up with weighted devices on bat velocity. They took sixty high school baseball players and had them swing thirteen different warm-up implements on separate days. The results showed that the warm-up implements leading to the greatest bat velocity were within ten percent of the game bat weight. They also reported that warming up by swinging a bat with a weighted donut, one of the most commonly utilized warm-up methods, resulted in the lowest subsequent bat velocity. In agreement with DeRenne’s 1992 study, a more recent study by Montoya and colleagues (2009) showed that warming up with a light bat (9.6 ounces) or a normal weight bat (31.5 ounces) produced significantly faster post-warm-up bat velocity than after warming up with a heavy bat (55.2 ounces).

A majority of weighted bat implements load the weight towards the barrel of the bat, increasing the moment of inertia (MOI) (Liu, Liu, Kao, & Shiang, 2011). The larger the MOI of the bat the more difficult it is to swing the bat at a high velocity while controlling hitting technique (Liu, Liu, Kao, & Shiang, 2011). This increase in the MOI of the bat combined with the dynamic nature of the weighted warm-up may disrupt the previously described kinetic chain link (Liu, Liu, Kao, & Shiang, 2011). As discussed, efficient kinematics always progress from the lower body, to the pelvis, trunk, arms, and then to the bat and ball (Shaffer, et al, 1993) and the transfer of
force and momentum can only be optimized if it is passed along at the right time. A study by Pillmeiera, Litzenbergera, and Saboa (2012) reported that the muscular recruitment pattern from the lower to the upper extremity according to the kinetic link principle is not seen when the bat is weighted, as the muscles of the upper body activated first. In addition, Southard and Groomer (2003) examined swing pattern and bat velocity after a warm-up with bats of different moments of inertia. Their results indicated that following a warm-up with the weighted bat (largest moment of inertia), swing pattern was significantly altered, and post warm-up bat velocity was the lowest of the three conditions. A weighted implement often causes players to prematurely go into forearm extension during the early phase of the swing (Pillmeiera, Litzenbergera, & Saboa, 2012), making it so that the hitter does not achieve slot position; casting the hands out away from the body, further increasing the moment of inertia and slowing bat velocity.

The acute effects of alternating bat weight are not only physical. A phenomenon referred to as the kinesthetic aftereffect is defined as a perceived modification in the shape, size, or weight of an object or a perceptual distortion of limb position, movement, or intensity of muscular contractions as a result of an experience with a previous object (Nakamoto, Ishii, Ikudome, & Ohta, 2012; Scott & Gray, 2010). Although it has been reported that subjective feelings, such as a faster swing speed, are advantageous to batting performance (DeRenne et al., 1992; Szymanski et al., 2011), the mismatch between subjective feelings and actual outcomes during the swing may reduce the perceptual-motor control of batters (Nakamoto, Ishii, Ikudome, & Ohta, 2012; Scott & Gray, 2010). A study by Nakamoto
and colleagues (2012) examined kinesthetic aftereffects of a weighted tool warm-up on interceptive performance. College baseball players performed three different warm-up protocols prior to swinging a standard weight bat corresponding with the arrival and position of a moving target, as done in baseball and softball. Researchers analyzed temporal error, or the difference between the time the moving target arrived in front of the plate and the time when the bat crossed it (Nakamoto, Ishii, Ikudome, & Ohta, 2012). The results showed that the warm-ups with a weighted bat created the greatest temporal errors (about 135 milliseconds) when hitters attempted to adjust to the moving target. They concluded that weighted tools can lead to adverse effects on movement programming and reprogramming processes when hitting a baseball (Nakamoto, Ishii, Ikudome, & Ohta, 2012). Timing of the sequential body segments during the swing is a practiced skill. Any warm-up disrupting the swing pattern and the sequence of releasing each component in the kinetic chain link would therefore be detrimental to bat velocity (Derenne, Ho, Hetzler, & Chai, 1992).

The research clearly indicates that proper sequencing of the body during the swing allows for the fluid motion that contributes to an explosive swing; while releasing segments, or going into forearm extension, too early can cause a decrement in bat velocity. Adding weight to a dynamic dry swing warm-up seems to have no benefit to subsequent bat velocity and can actually unfavorably alter swing pattern and cause timing errors during ensuing swings. Therefore, a warm-up protocol in which the hitter does not wield a heavy implement, but still potentiates the muscles involved in the swing, may successfully increase bat velocity while
allowing for proper timing and successful batting performance. Using a heavy preload stimulus as a warm-up prior to an explosive task follows the method of attempting to utilize the post-activation potentiation (PAP) phenomenon. However, for a potentiating warm-up protocol to be successful, the science and principles behind PAP must be adequately understood and controlled.

**Post-activation Potentiation**

The contractile response of skeletal muscle is affected by its history of activation. The most evident effect of contractile history is fatigue, which impairs performance. However, the prior activation of skeletal muscle can also enhance the voluntary production of force; a phenomenon known as post-activation potentiation (Hodgson, Docherty, & Robbins, 2005; Tillin & Bishop, 2009). Post-activation potentiation (PAP) is the enhancement of muscle function following a specific preload activity, typically performed at maximal, or near maximal, intensity (Hodgson, Docherty, & Robbins, 2005). After an intense volitional or electrically induced stimulus, the muscles involved are both fatigued and potentiated (Rassier & MacIntosh, 2000). Subsequent performance of the muscles is dependent on the interplay of these two factors. Optimal performance would occur if fatigue subsides, but potentiation still exists. PAP has been well demonstrated throughout the literature by an increase in peak power (Esformes, Keenan, Moody, & Bampouras, 2011; Kilduff, et al., 2007; Rixon, Lamont, & Bemben, 2007) and RFD (Esformes, Keenan, Moody, & Bampouras, 2011; Gilbert & Lees, 2005; Gullich & Schmidtbleicher, 1996) during the potentiated activity, after a sufficient recovery. According to the literature, peak power can increase anywhere from 2% to 8%
(Kilduff, et al., 2007; Rixon, Lamont, & Bemben, 2007) and RFD can increase up to 13% (Gilbert & Lees, 2005). The characteristics of both the potentiating exercise and the individual athlete are vitally important to the effectiveness of the PAP protocol.

**Mechanisms of PAP**

The possibility that a conditioning contraction may be utilized to enhance subsequent athletic performance has received considerable attention. However, the mechanisms which modulate this phenomenon have been investigated to a lesser extent and have not yet been fully elucidated (Folland, Wakamatsu, & Fimland, 2008). Various theories have been hypothesized in the literature, but the primary mechanism continues to be debated. The inconsistency among reports justifies a thorough review of the literature. Identifying the mechanism(s) facilitating an increase in peak force production and RFD could promote the development of strategies to optimize the use of PAP to augment performance.

Skeletal muscle physiologists have been researching twitch potentiation (TP) and reflex potentiation (RP) for decades, in both human and non-human mammals. Over time, numerous theories regarding the mechanisms of PAP have been hypothesized. The many proposed mechanisms include enhanced muscle blood flow, psychomotor enhancement, Golgi tendon organ disinhibition, increased muscle spindle firing rate, increased synergist activity, decreased antagonist recruitment, decreased pennation angle of the muscle, increased motor neuron activity, and increased myosin light chain phosphorylation. In order to identify the primary mechanism responsible for PAP from the several proposed theories,
unlikely mechanisms will be separated from the two more likely mechanisms, based on their support in the literature. The possible contributing and primary mechanisms are discussed in more detail.

**Unlikely mechanisms.** There are many mechanisms proposed in the literature which have more evidence refuting than supporting them. The least likely of these theories is the idea that a potentiating exercise increases blood flow to the muscle in order to enhance the performance of the subsequent activity (Magnus et al., 2006). This particular explanation of PAP is not well supported because the subsequent activity would be a primarily anaerobic explosive power movement, meaning that there would be little to no benefit in receiving more oxygen from the blood. Another suggested theory is that the pre-load activity causes psychomotor enhancement (Ebben, Jensen, & Blackard, 2000). Psychomotor is referring to the motor effects of psychological processes, or a motor skill being affected by sensory or perceptual motor coordination. Despite this suggestion, there has been no evidence of this occurring with or contributing to PAP.

Decreased pennation angle of the muscle as a result of a conditioning contraction has also been proposed as a potential mechanism to facilitate PAP. This idea originated from a study by Mahfeld and colleagues (2004) that examined the pennation angle of the vastus lateralis before and after three second isometric maximum voluntary contractions (MVCs). They found that three to six minutes after the MVCs, the pennation angle of the muscle had significantly decreased. A decrease in pennation angle would increase the mechanical advantage, leading to an increase in force production. However, this change would only be equivalent to a 0.9%
increase in force transmission to the tendons (Mahfeld, Franke, & Awiszus, 2004), not enough to be the primary mechanism of PAP.

Other mechanisms which have been proposed include Golgi tendon organ disinhibition, increased muscle spindle firing rate, increased synergist activity, and decreased antagonist recruitment (Wilson, Gandevia, & Burke, 1995). These have been refuted by the research on twitch potentiation, as they either do not contribute or do not have a strong enough influence to be the primary model responsible for the potentiation that can be seen after a pre-load stimulus. In sum, the concepts proposed above are not well supported in the literature as being the primary mechanism for PAP. More likely are one of the following two theories.

**Reflex potentiation (RP).** A more commonly cited model of explaining PAP involves enhanced neural drive to the agonist musculature, as measured by the Hoffmann Reflex (H-Reflex). The H-reflex is an estimate of la afferent activation of the alpha motoneuron (aMN) when presynaptic inhibition and intrinsic excitability of the aMNs remain constant (Palmieri, Ingersoll, & Hoffman, 2004). An H-wave, measuring the H-reflex, is the result of an action potential (AP) traveling along the afferent neural fibers to the spinal cord, where the AP is transmitted to adjacent efferent neural fibers, and subsequently down to the muscle itself (Tillan & Bishop, 2009). This twitch response is seen in the electromyography (EMG) of the targeted muscle. The idea behind this theory is that the potentiating exercise intervention augments the H-reflex, increasing the efficiency and frequency of the nerve impulses to the muscle, as well as increasing motor unit recruitment.
Research, mainly using non-human mammals, shows that an induced tetanic, or sustained, contraction elevates the transmittance of excitation potentials across synaptic junctions at the spinal cord (Folland, Wakamatsu, & Finland, 2008; Trimble & Harp, 1998). This state of increased transmittance, or decreased transmission failure, can last for several minutes after the tetanic contraction and results in an increase in post-synaptic potentials for the same pre-synaptic potential during any subsequent activity (Tillin & Bishop, 2009). Hirst and colleagues (1981) supported this claim, as they stimulated the afferent neural fibers of a cat via a twenty second tetanic isometric contraction. They found a fifty-four percent increase in excitatory post-synaptic potentials (EPSPs) for the same pre-synaptic stimulus. Luscher and colleagues (1983) also found EPSPs increased at cat aMNs after an electrically induced ten second tetanic contraction. Additionally, these authors found that a tetanic contraction decreased the transmitter failure occurring primarily at larger motor neurons, resulting in a PAP effect at these motor neurons (Luscher, Ruenzel, & Henneman, 1983). Larger motor neurons are responsible for activation of higher order fast twitch motor units. These findings are important, because if a conditioning contraction could elicit augmented motor unit recruitment, this would increase type II muscle fiber contribution to the contraction and enhance the force production of the subsequent activity (Tillan & Bishop, 2009). However, the understanding of reflex potentiation (RP) following voluntary contractions is very limited.

Two studies have examined RP after voluntary effort in humans. Gullich and Schmidtbleicher (1996) found significant RP for speed-strength athletes, but not
untrained individuals, lasting five to thirteen minutes after isometric MVCs. The implication of these findings, however, is overshadowed by the study's limited methodology. Gullich and Schmidtbleicher (1996) did not indicate their method for establishing stimulus constancy nor did they normalize the H-wave amplitude to the maximal M-wave. The M-wave represents the synchronous electrical activity of all muscle fibers following an electrical stimulus (Robertson, Caldwell, Hamill, Kamen, & Whittlesey, 2004). Failing to normalize the H-wave means that factors not related to central activation may be responsible for the results of this particular study. A more detailed study observed normalized H-reflex potentiation of the lateral gastrocnemius, but not the soleus, three to ten minutes after an intense bout of volitional resistance exercise consisting of eight sets of dynamic MVCs (Trimble & Harp, 1998). Nevertheless, the mechanical consequences, or force response, of these changes in electrically measured RP have not been assessed.

Given the evidence, increased reflex transmission between la afferents and alpha motor neurons, as reflected by an augmented H-reflex, may enhance volitional force production by optimizing the reflex contribution to neural drive. As it has not been measured concurrently, this would only theoretically enhance the RFD and force production during high velocity movements. Furthermore, while frequently utilized as a measurement tool to estimate spinal reflex processing, it should be noted that a number of methodological limitations exist that can influence the interpretation of the H-reflex (Hodgson, Docherty, & Robbins, 2005). Despite the significant findings in the previously mentioned studies, the limitations associated with using the H-reflex may render it an invalid measurement tool, and therefore
these results should be approached with caution. Taken together, there is little
evidence to confirm that this is the primary mechanism responsible for PAP.

**MLC Phosphorylation.** The most widely accepted mechanism for mediating
the PAP phenomenon involves an increased phosphorylation of myosin regulatory
light chains as a result of a maximum, or near maximum, voluntary contraction. In
muscle cells, sarcomeric contraction results from the calcium (Ca\(^{2+}\)) regulated
binding of myosin to actin (Kamm & Stull, 2011). A myosin molecule is composed of
two myosin heavy chains as well as two small protein subunits, the essential light
chain and regulatory light chain (RLC). These light chains are positioned at the neck
of the myosin head, providing it mechanical stability (Kamm & Stull, 2011). Each
myosin light chain can incorporate a phosphate molecule which alters the structure
of the myosin head. The myosin RLCs can become phosphorylated after an intense
contraction (Sweeney, Bowman, & Stull, 1993; Szczesna et al., 2001). This occurs
because the pre-load stimulus saturates the cell with increased Ca\(^{2+}\). Ca\(^{2+}\) released to
the sarcomeres may bind with calmodulin and subsequently activate
Ca\(^{2+}\)/calmodulin-dependent skeletal myosin light chain kinase (skMLCK) which, in
turn, phosphorylates the RLC (Stull, Kamm, & Vandenboom, 2011). Presumably, the
increased RLC phosphorylation causes increased Ca\(^{2+}\) sensitivity of the myofilments,
thus enhancing the submaximal contractile response (Ryder, Lau, Kamm, & Stull,
2007; Sweeney, Bowman, & Stull, 1993; Szczesna et al., 2001). Greater submaximal
force from high levels of RLC phosphorylation results from an increased rate of
cross-bridge attachment and transition of the cross-bridges to a strongly bound,
force-generating state (Davis, Satorius, & Espstein, 2002; Kamm & Stull, 2011; Stull, Kamm, & Vandenboom, 2011).

This model of twitch potentiation has been supported in multiple studies, dating back nearly thirty years. But again, twitch potentiation has been largely studied in response to electrical stimuli in mainly non-human mammals and in skinned fiber preparations. Vandenboom & Houston (1996) examined potentiated twitch forces during fatigue of mouse skeletal muscle. These authors used 120 second tetanic contractions to induce fatigue. Though decreases in twitch force were observed initially, they found that this conditioning stimulus potentiated the muscle after a rest period. They also reported that the amount of potentiation was highly correlated with the amount of RLC phosphorylation. Sweeney, Bowman, and Stull (1993) reported similar findings. They observed that in skinned fibers, RLC phosphorylation increases force production at low levels of Ca\(^{2+}\) activation, through a leftward shift of the force-pCa relationship. They also found that phosphorylation correlates with the extent of potentiation as measured by maximal isometric twitch tension and rate of force development. Szczesna and colleagues (2001) reported that twitch force increased significantly when non-phosphorylated fibers became phosphorylated with exogenous myosin light chain kinase. In accordance with all of the above findings, Vandenboom, Grange, and Houston (1995) found that in skinned fiber models, values obtained for twitch and tetanic force after a conditioning contraction were strongly correlated to the phosphate content of the myosin regulatory light chains in fast-twitch skeletal muscle. Taken together, these results show that phosphate incorporation by myosin RLC, due to an electrically induced
stimulus, contributes to an enhanced rate of isometric force and rate of force development in fast-twitch skeletal muscle. Unfortunately, much less is known about the effects of PAP on voluntary contractions.

A limited number of studies have investigated the mechanisms of PAP after fast voluntary contractions in humans. Some groups have reported enhanced muscular performance following strong conditioning contractions (French, Kraemer, & Cooke, 2003; Gullich & Schmidtbleicher, 1996; Smith & Fry, 2007), while others have reported no effect (Hyrsomallis & Kidgell, 2001). Additionally, Behm and colleagues (2004) found that voluntary and evoked contractions respond differently to previous ten-second MVCs. Clearly, voluntary contractions seem to be more complex and difficult to control in terms of measuring both PAP and RLC phosphorylation. Accounting for the methods of the research, even fewer studies give valid findings for the connection of the aforementioned variables.

**Evidence for the primary mechanism.** Despite the inconclusive reports in the research, the studies expose more about the potential mechanism than it seems. In the body of literature exploring PAP, some criteria for the primary mechanism have emerged. There is strong evidence indicating that the mechanism is likely intramuscular, calcium dependent, and associated with greater potentiation of type II muscle fibers (French, Kraemer, & Cooke, 2003; Klein, Ivanova, Rice, & Garland, 2001; Palmer & Moore, 1989; Ryder et al., 2007).

Evidence supporting that the mechanism is likely intramuscular is seen a study that found a conditioning contraction (five-second contraction of the triceps brachii at 75% of maximum voluntary force) elicited a significant twitch force
potentiation with a simultaneous decline in motor unit discharge rate (Klein, Ivanova, Rice, & Garland, 2001). In agreement with this finding, French and colleagues (2003) failed to observe a concurrent increase in EMG where an increase in force output occurred as a consequence of potentiation. These results support the model of RLC phosphorylation and that mechanism responsible for PAP operates within the muscle.

The idea that mechanism of PAP is calcium dependent is substantiated in a study done by Palmer and Moore (1989). Here, the researchers used intact mammalian fast-twitch skeletal muscle of mice and experimentally decreased the amount of calcium available to the contractile element. To accomplish this they used sodium dantrolene, which inhibits Ca\(^{2+}\) release from the sarcoplasmic reticulum. With the treatment of dantrolene, Palmer and Moore found that twitch tension decreased by 73%. This indicates that the amount of calcium released from the sarcoplasmic reticulum is directly related to the amount of twitch potentiation that occurs and gives support to the model of increased RLC phosphorylation mediating PAP.

It is widely reported that potentiation occurs almost selectively in type II fast twitch fibers in small mammals, as type II fibers exhibit greater posttetanic twitch force potentiation than muscles with longer twitch contraction times and a predominance of slow-twitch, type I fibers. This may be due to the finding that there is significantly greater skMLCK expression in fast-twitch (type IIa and IIb) muscle fibers (Ryder et al., 2007; Zhi et al., 2005). A study examining transgenic mouse lines found that the lines expressing greater type II fibers showed a more rapid RLC
phosphorylation and force potentiation (Ryder, et al., 2007). The same concept seems to hold true in humans (Hamada, Sale, MacDougall, & Tarnopolsky, 2000; Houston, Green, & Stull, 1985). One study found that positive correlations exist between the extent of twitch potentiation, phosphate content of individual RLC, as well as the percentage of type II muscle fibers in vastus lateralis muscle in humans (Stuart, Lingley, Grange, & Houston, 1988). Together these findings, too, point to increased phosphorylation of the RLC as the primary mechanism modulating PAP.

Furthermore, in order for the mechanism to be responsible for PAP, it must correlate with the amount of potentiation that is occurring, explain how the potentiation can outlast fatigue effects, and clarify how this mechanism can create a force generating state, leading to increased peak force and rate of force development. RLC phosphorylation continues to be well supported here. As previously discussed, many studies have reported strong correlations ($r = 0.97$) between the level of RLC phosphorylation and the percentage of potentiation occurring (Grange, Cory, Vandenboom, & Houston, 1995; Vandenboom, Grange, & Houston, 1995; Vandenboom & Houston, 1996). Research has also explained how potentiation remains beyond the effects of fatigue. Phosphorylation dissipates slowly due to the slow activity of myosin light chain phosphatase which removes the phosphate from the RLC (Stull, Kamm, & Vandenboom, 2011). Moore and Stull (1984) found that the rate of dephosphorylation was four times faster in slow twitch muscle than in fast twitch muscle; another reason why potentiation may be seen primarily in fast twitch muscle. Additionally, it has been shown that RLC phosphorylation increases peak force and RFD by increasing cross-bridge transition
to a strongly bound, force generating state (Baudry & Duchateau, 2007; Davis, Satorius, & Espstein, 2002; Rassier & Macintosh, 2000). Davis, Satorius, and Espstein (2002) suggest that regulatory light chain phosphorylation up-regulates the flux of weakly attached cross-bridges entering the contractile cycle by increasing the actin-catalyzed release of phosphate from myosin. It has also been reported that increased MLC phosphorylation increases the speed of cross-bridge cycling and therefore leads to a greater rate of force development (Rassier & Macintosh, 2000). In summary, evidence suggests that phosphate incorporation by skeletal myosin RLC contributes to twitch potentiation and augmented force development in fast-twitch skeletal muscle.

**Summary of mechanisms.** Through an extensive review of the literature, it can be concluded that, of the many hypothesized mechanisms, increased phosphorylation of myosin regulatory light chains is associated with and at least partly responsible for PAP. Given that it is the only well supported mechanism in the research, this may be the primary model supporting the PAP phenomenon. Though enhanced neural drive to the agonist musculature is often cited as a potential underlying mechanism, there has been no increase in nervous (Klein, et al., 2001) or EMG (French, Kraemer, & Cooke, 2003) activity when simultaneous PAP occurs. However, Stull and colleagues (2011) suggest that RLC phosphorylation-mediated enhancements may interact with neural strategies for human skeletal muscle activation to outlast aspects of fatigue. It does seem possible that other mechanisms may work together with RLC phosphorylation to contribute to PAP, but clearly, more research is needed. The uncertain results surrounding voluntary conditioning
contractions and PAP may be due to the complex interaction of numerous variables that determine the degree to which potentiation and fatigue are affected.

**Inducing Potentiation**

Many factors can influence the presence of PAP, including the load, volume, and type of the potentiating activity, the duration of rest between the potentiating and the potentiated activity, the muscles involved in both activities, and the training status of the individual, as well as their fiber type distribution (Folland, Wakamatsu, & Fimland, 2008; Gullich & Schmidtbleicher, 1996; Hodgson, Docherty, & Robbins, 2005; Smith & Fry, 2007; Tillin & Bishop, 2009). The optimal levels of each of these variables are widely debated in the research and have yet to be standardized.

**Subject characteristics.** Before the load, volume, and type of the potentiating activity are considered, it is critical to evaluate the training level of the individual. The potentiated response after a conditioning activity is typically seen in highly trained athletes and does not usually occur in untrained or recreationally trained subjects. Rixon, Lamont, and Bemben (2007) reported that experienced weight lifters responded better to a conditioning contraction and exhibited greater PAP than the inexperienced lifters. Similarly, Chiu and colleagues (2003) looked at the PAP response in athletic and recreationally trained individuals. All subjects performed jump squats five minutes and eighteen and a half minutes after a heavy load warm-up, which consisted of five sets of one back squat performed at ninety percent of the individuals’ one repetition maximum (1RM). The study reported that percent potentiation, defined as the potentiated variable divided by the un-potentiated variable multiplied by one-hundred, for both force (average force, peak
force, and rate of force development) and power (peak power and average power) parameters were significantly (5-10%) greater for the athletic group following the experimental warm-up when compared to the recreationally trained group. In fact, the athletic group exhibited greater than 100% potentiation at all experimental loads for all force and power parameters, whereas performance for the recreationally trained group was near or below 100% (Chiu, et al., 2003). Gullich and Schmidtbleicher (1996) also reported differences between recreationally trained and speed-strength trained individuals, stating that the highly trained subjects exhibited significantly longer lasting (2.2 minutes longer) potentiation when compared to the recreationally trained subjects. Interestingly when the subject characteristics of many PAP studies are compared, studies evaluating trained individuals report enhanced muscle performance (Baker, 2003; Chatzopoulos, et al., 2007; Kilduff, et al., 2007; Weber, Brown, Coburn, & Zinder, 2008; Young, Jenner, & Griffiths, 1998), while research assessing untrained or recreationally trained individuals shows no increase or a decrement in performance measures (Brandenburg, 2005; Khamoui, et al., 2009, Magnus, et al., 2006, Smith & Fry, 2007).

In addition to training experience, relative (REL) and absolute (ABS) strength appears to influence PAP. Kilduff, et al., (2007) investigated the effect of strength on the presence of PAP in rugby players and found that a significant correlation exists between 3-RM strength and the amount of potentiation that occurred twelve minutes after a high intensity warm-up in both the lower body ($r = 0.631, p = 0.009$) and upper body ($r = 0.590, p = 0.004$). Kilduff, et al., (2007) also reported a
significant positive correlation \( (r = 0.631, p = 0.009) \) between lower-body relative strength (3-RM divided by body mass) and the potentiation occurring twelve minutes post-exercise. Young, Jenner, and Griffiths (1998) found that a loaded countermovement jump could be significantly enhanced if preceded by a set of half-squats with a five repetition maximum load. They reported a significant correlation \( (r = 0.73, p = 0.02) \) between the subjects’ five repetition maximum and the subsequent performance enhancement, implying that individuals who are stronger may be better able to take advantage of the PAP phenomenon. In fact, Baker (2003) reported that the two strongest subjects participating in his study, analyzing upper body PAP, increased their power output by an average of 6.2% after the potentiating protocol (six-repetition set of bench presses at 65% 1RM), while the two weakest subjects only saw an increase of 0.8%. Multiple studies have reported the presence of PAP using both male and female subjects (Chiu, et al., 2003; Gullich & Schmidtbleicher, 1996; Rixon, Lamont, & Bemben, 2007). Duthie, Young, and Aitken (2002), who utilized only female subjects to examine the acute effects of heavy loads on jump squat performance, separated their subjects into two groups relative to their predicted 1-RM strength levels. They found a significant difference in performance changes, following the potentiating stimulus, between the higher and lower strength groups, with the higher strength group having a greater improvement in jump squat performance (4% increase in peak power and 2% increase in maximal force). The results of these studies show that there is no effect of sex on PAP, as long as the subject is a well-trained athlete.
The above findings may be explained by greater fatigue resistance in trained subjects, when compared to untrained subjects, following a conditioning activity, typically performed at high intensities. If fatigue outlasts potentiation, any performance enhancement would be negated. Highly trained individuals may also be better able to take advantage of the increased recruitment of higher threshold motor units (composed of fast-twitch fibers) to perform work, while untrained individuals may not have developed those motor units. Athletes with a higher percentage of type II muscle fibers tend to respond better to PAP, as potentiation is more likely to outlast fatigue in fast twitch fibers due to higher concentrations of skMLCK and slower rates of dephosphorylation of the RLC (Hamada, Sale, MacDougall, & Tarnopolsky, 2000; Houston, Green, & Stull, 1985). Because positive correlations exist between the extent of potentiation, the amount of phosphorylation that occurs, and the percentage of type II muscle fibers (Stuart, Lingley, Grange, & Houston, 1988), it could be said that trained individuals demonstrate elevated myosin RLC phosphorylation activity when compared to untrained subjects (Wilson, et al., 2013). In general, an individual needs to be reasonably strong in order to take advantage of PAP and it is likely that the balance between fatigue and potentiation are more favorable when a subject is well trained. This shows that PAP may be a viable method of acutely enhancing explosive strength performance in well-trained individuals.

**Intensity and volume.** During the repetitive stimulation of a conditioning contraction, two opposing processes are occurring simultaneously; one that enhances muscle function and one that causes a reduction in muscle function
Banister and colleagues (1992), who provided a fitness fatigue model for human performance, suggested that the training impulse leads to the buildup of both fitness and fatigue in the athlete and that performance is a result of the difference between the two variables. For a specific conditioning activity, the impulse is calculated by the intensity (percent of 1-RM) multiplied by the volume performed (Banister, Morton, & Fitz-Clarke, 1992).

Several potentiation protocols have investigated the effects of maximal and submaximal muscle activity on subsequent athletic performance. Usually, PAP is induced by an application of resistance training stimuli (preload), such as a heavy load squat (Chiu, Fry, Weiss, Schilling, Brown, & Smith, 2003; Webber, Brown, Couburn, & Zender, 2008; Young, Jenner, & Griffiths, 1998) or a maximal voluntary isometric contraction (French, Kraemer, & Cooke, 2003; Gullich & Schmidtbleicher, 1996; Rixon, Lamont, & Bemben, 2007). Research shows that high intensity loads are necessary for potentiation to occur. Though this may be partially dependent on the training status of the individual, it seems as though the load must be greater than sixty percent of an individual’s dynamic or isometric maximum voluntary contraction in order to elicit this phenomenon (Hodgson, Docherty, & Robbins, 2005; Tillin & Bishop, 2009). Throughout the literature, performance enhancement is usually seen when the potentiating load is between eighty-five and one-hundred percent 1RM (Chiu, et al., 2003; Gullich & Schmidtbleicher, 1996; Kilduff, et al., 2007; Rixon, Lamont, & Bemben, 2007; Webber, Brown, Couburn, & Zender, 2008; Young, Jenner, & Griffiths, 1998).
Young, Jenner, and Griffiths (1998) reported that a single set of squats performed with a 5-RM load significantly increased countermovement jump (CMJ) height by 2.6%, after a four minute recovery in athletes with squat exercise experience. Kilduff et al. (2007) also found a significant improvement in CMJ performance (8% increase in lower body peak power output) using a squat potentiating protocol consisting of three sets of three repetitions at eighty-seven percent of the subjects 1-RM. Similarly, Webber, Brown, Couburn, and Zender (2008) reported that one set of five repetitions of a back squat performed at eighty-five percent of 1-RM significantly enhanced squat jump height in track and field athletes (pre: 41.6 ± 5.3 cm; post: 43.9 ± 5.1 cm). Hanson, Leigh, and Mynark (2007), conversely, found that a single squat performed at eighty percent of 1-RM does not improve vertical jumping performance when measured immediately after the potentiation protocol in resistance trained athletes. Here, Hanson and colleagues (2007) showed that the induction of PAP depends not only on the intensity, but also on the volume and recovery of the potentiating protocol.

The suggested volume of the conditioning activity varies widely in the research. Completing as few as one set, and up to five sets, of a conditioning activity has been successful in eliciting potentiation, however, it seems as though multiple sets result in a greater augmentation of power than single sets (Hodgson, Docherty, & Robbins, 2005; Tillin & Bishop, 2009). Sets consisting of greater than five total repetitions or a total contraction time longer than five seconds appear to induce higher than preferable levels of fatigue (French, Kraemer, & Cooke, 2003; Gullich & Schmidtbleicher, 1996). Alternatively, sets of four repetitions, or a total contraction
time of five seconds or less, can limit fatigue while still inducing potentiation (French, Kraemer, & Cooke, 2003; Gullich & Schmidtbleicher, 1996; Kilduff, et al., 2007). Behm and colleagues (2004) implemented a conditioning contraction protocol examining the effects of one, two, and three sets of ten second isometric MVCs and found either no change or a significant decrement in performance, after one, five, ten, and fifteen minutes of recovery. The results of this study show that high volumes may induce muscle fatigue, overwhelming any potentiation that may be simultaneously present. Regarding isometric conditioning contractions specifically, the literature suggests that three to five MVCs, lasting no longer than five seconds each, can provide sufficient stimuli to induce potentiation in athletes (Gullich & Schmidtbleicher, 1996; Tillin & Bishop, 2009).

**Recovery time.** Studies on twitch potentiation report maximal PAP instantaneously post-exercise, as phosphorylation of RLCs is also highest immediately following the conditioning contraction (Moore & Stull, 1984). Fatigue, however, is also present at this time and seems to be more dominant than potentiation in the early phases of recovery (Tillin & Bishop, 2009). Recovery duration following an intense exercise has a considerable influence on fatigue, as well as the performance of any subsequent activity. Following a conditioning exercise, fatigue may be elicited via a depletion of substrate, an accumulation of hydrogen ions, or a mechanical disruption of the myofibrillar architecture. Fatigue experienced after a short, intense bout of exercise is often associated with the selective depletion of phosphagens (ATP and creatine phosphate), crucial to short-term maximal exercise performance. Intense activity can result in a marked
decrease in the muscle content of phosphocreatine (PCr), while only a slight change in ATP content may occur (Harris, Edwards, Hultman, Nordesjo, Nylin, & Sahlin, 1976). The magnitude of the reduction in PCr varies with the type and intensity of the exercise performed, and under certain circumstances is correlated with the increase in muscle lactate content (Dawson, et al., 1997). Although the duration of recovery influences the removal of lactate, the half-time for this process is approximately nine minutes and seems to have little effect during short-term recovery prior to an explosive activity (Glaister, Stone, Stewart, Hughes, & Moir, 2005). Power output, however, is dependent on the repletion of PCr (Glaister, et al., 2005).

Harris, et al. (1976) analyzed the time course of PCr re-synthesis in the quadriceps femoris during recovery from exhaustive dynamic exercise and isometric contractions sustained to fatigue. The authors reported that the immediate post-exercise muscle PCr content after either type of fatiguing exercise was only fifteen to sixteen percent of the resting intramuscular PCr stores. For both protocols, PCr repletion was not fully complete after four minutes of recovery. Similarly, Dawson, et al. (1997) measured PCr re-synthesis following either single (one six second sprint) or repeated (five, six second sprints, with thirty seconds of rest in between) maximal short sprint cycling efforts. Muscle biopsies of the vastus lateralis were taken pre-exercise prior to warming up, and then at ten seconds, thirty seconds, and three minutes post-exercise. Results showed that after the single bout sprint, PCr concentration, when compared to pre-exercise values, was 55% after ten seconds, 69% after thirty seconds, and 90% after three minutes; whereas
after the repeated sprints, PCr concentration was 27% at ten seconds, 45% at thirty seconds, and 84% after three minutes. Just as in the previously mentioned study, full repletion of PCr stores took longer than the time allotted (three and four minutes).

Full repletion of PCr is likely to take longer after repeated sprints, or higher volume work, because the greater degree of PCr depletion during the activity. Replenishment, then, must begin from lower levels of PCr in the muscle. Interestingly, trained individuals usually have greater muscle creatine stores (MacDougall, Ward, Sale, & Sutton, 1977), implying that a conditioning contraction may not fully deplete their PCr stores and therefore trained persons may reach replenishment more quickly than untrained individuals. Additionally, resting intramuscular PCr content is higher in fast twitch muscle fibers than in slow twitch fibers (Tesch, Thorsson, & Fujitsuka, 1989). As PCr depletion is closely associated with fatigue (Hirvonen, Nummela, Rusko, Rehunen, & Härkönen, 1992) this may be another reason why well trained athletes with a greater distribution of type II muscle fibers are better able to take advantage of PAP.

Post-exercise deficit in intra-muscular PCr stores is likely a contributing factor to the observed fatigue following a potentiating stimulus. If PCr stores are not recovered prior to a subsequent activity, any potentiation may be negated and performance may decline as the rate of ATP re-synthesis will not be as rapid with less PCr available for energy metabolism. ATP must then be provided from glycolytic and aerobic energy pathways. For the acute augmentation of muscle performance to occur following a heavy pre-load stimulus, the phosphorylation of myosin RLCs must be able to outlast the repletion of phosphagen stores in the
muscle (Tillin & Bishop, 2009). Re-synthesis of phosphocreatine stores usually occurs between four and eight minutes post-exercise (Behm, et al., 2005; Harris, et al., 1976), while the time-course for the rate of dephosphorylation of myosin RLCs, via the slow activity of myosin light chain phosphatase, seems to be around twelve minutes (Moore & Stull, 1984); however potentiation has occasionally been realized in durations up to twenty minutes (Tillin & Bishop, 2009). This shows that in trained individuals, fatigue may subside before potentiation dissolves, creating a window of opportunity for PAP to exist.

When examining the research, there seems to be a relationship between chemical recovery in muscle and the recovery and augmentation of muscle performance. In accordance with the typical PCr repletion and myosin RLC dephosphorylation times given above, literature suggests that the optimal recovery duration following a conditioning contraction for subsequent explosive performance is between eight and twelve minutes (Kilduff, et al., 2007). Previous studies have used recovery periods ranging from ten seconds to twenty minutes. When post-exercise recovery periods less than eight minutes are utilized, fatigue may negate the potentiation. Jensen and Ebben (2003) examined the effect of a 5-RM squat protocol on a CMJ after recovery periods of ten seconds and one, two, three, and four minutes. The authors reported a decrement in power output during the CMJ immediately following the resistance exercise and no significant difference in power outputs at any time thereafter. However, the authors did report a non-significant trend toward an improvement in performance and suggested that a significant increase in power output may have occurred beyond four minutes of
recovery. Kilduff and colleagues (2007), specifically focused on the optimal recovery time required to observe enhanced muscle performance following a preload stimulus using well trained athletes. Analyzing peak power output (PPO) during CMJs and ballistic bench throws, researchers measured at baseline, fifteen seconds, and four, eight, twelve, sixteen, and twenty minutes post-exercise. There was a significant decrease in PPO for both the upper (-4.7%) and the lower (-2.9%) body when the explosive activity was performed fifteen seconds after the preload stimulus. However, once a recovery period of twelve minutes was allowed, PPO for CMJ and ballistic bench throws increased by 8% and 5.3% respectively (Kilduff, et al., 2007).

Only one study has examined the effects of various warm-up devices and rest period lengths (one, two, four, and eight minutes) on bat velocity. Wilson and colleagues (2012), using college baseball players, found no significant effects on bat velocity from any of the weighted warm-up devices and therefore pooled the peak value data together when looking at effects of recovery time. The analysis revealed that peak bat velocity increased significantly, from a baseline average of about thirty-seven meters per second (m/s) to 38.75 m/s, after a rest period of two minutes; bat velocity increased again at four minutes (39.25 m/s), and peaked at eight minutes (40 m/s). The shorter than typical time to observed potentiation in these athletes may be due to the low load of the potentiating activity. The time to peak bat velocity, however, does agree with the findings of Kilduff, et al. (2007), in that optimal recovery occurs between eight and twelve minutes post-exercise.
Longer recovery periods will usually not be successful, as the potentiation will diminish over time. However, there may be a wider window for potentiation in elite athletes (Hodgson, Docherty, & Robbins, 2005; Kilduff, et al., 2007). If PCr re-synthesizes more quickly, as it seems to in well-trained individuals, the optimal window for recovery would begin earlier post-exercise. A well-trained athlete may experience potentiation as early as four minutes post-exercise, depending on the intensity and volume of the potentiating exercise (Gullich & Schmidtbleicher, 1996; Jensen & Ebben, 2003; Kilduff, et al., 2007; Wilson, et al., 2012). Additionally, if greater phosphorylation occurs, as it appears to in athletes, potentiation could last longer. Rest durations lasting from four to twenty minutes following a potentiating stimulus have exhibited power performance enhancement for elite athletes (Gilbert & Lees, 2005). In untrained or recreationally trained individuals, a time window for potentiation may not exist because the re-synthesis of substrate may take longer than the dephosphorylation of the myosin RLCs (Brandenburg, 2005; Khamoui, et al., 2009, Magnus, et al., 2006, Smith & Fry, 2007). Before implementing a PAP warm-up protocol in a performance setting, it seems necessary to determine, individually, the most advantageous interval between conditioning contractions and the subsequent performance (Gullich & Schmidtbleicher, 1996).

**Type of Potentiating Exercise.** Various conditioning contractions have elicited PAP during whole-body explosive movements in well-trained athletes (French, Kraemer, & Cooke, 2003; Gullich & Schmidtbleicher, 1996; Hodgson, Docherty, & Robbins, 2005; Kilduff, et al., 2007; Tillin & Bishop, 2009; Weber, Brown, Coburn, & Zinder, 2008; Young, Jenner, & Griffiths, 1998). Examples of
conditioning contractions used in the research include short-duration maximal, or near maximal, isometric actions (French, Kraemer, & Cooke, 2003; Gullich & Schmidtleicher, 1996; Rixon, Lamont, & Bemben, 2007) and a brief series of high intensity dynamic resistance activity (Kilduff, et al., 2007; Weber, Brown, Coburn, & Zinder, 2008; Young, Jenner, & Griffiths, 1998). Research suggests that the potentiating protocol may be isometric or dynamic, as long as the intensity and duration of the contraction is adequate to increase phosphorylation of the myosin RLC. Dynamic potentiation exercise protocols are more popular in the literature and frequently utilized as a part of complex training. Among these exercises, the back squat and the bench press are most commonly used to induce potentiation (Hodgson, Docherty, & Robbins, 2005; Tillin & Bishop, 2009). The notion that voluntary isometric conditioning contractions can be used to facilitate increased performance of dynamic whole-body activity has been studied to a lesser extent.

French, Kraemer, and Cooke (2003) examined the effects of a heavy load preconditioning stimulus of maximal isometric knee extensions on dynamic whole-body exercise, including drop and countermovement jumps, five-second cycle sprint, and knee extension. Researchers reported significant increases in jump height (5.03%), maximal force (4.94%), and acceleration impulse (9.49%) in the drop jump following three repetitions of three-second MVCs. Gullich and Schmidtleicher (1996) also found significant improvements in jump height (3.3%) during CMJs following a preconditioning sequence of multiple isometric MVCs. Some research suggests using isometric activities to elicit potentiation, over dynamic protocols. Rixon and colleagues (2007) examined the influence of muscle
contraction type (isometric versus dynamic) on PAP, as demonstrated by changes in jump height and power output after each potentiating protocol. These authors found that the isometric squat protocol evoked a greater percent change in jump height (2.2%) and peak power output (8.4%) than the dynamic squat condition (0.7% and 7.4% respectively). Esformes and colleagues (2011) recently supported this concept, stating that an isometric conditioning contraction induced PAP after a twelve minute recovery period, while dynamic conditions did not. This may be due to a previous finding that when compared to isometric muscle actions, dynamic exercise requires more metabolic energy and can cause greater depletion of PCr (Bridges, Clark, Hammond, & Stephenson, 1991); suggesting that isometric muscles actions may produce less fatigue to overcome during recovery. It has also been reported that isometric contractions activate a greater number of motor units than dynamic contractions (Tillin & Bishop, 2009). If this is true, an isometric contraction may involve more muscles fibers, possibly resulting in greater phosphorylation of the RLCs. Theoretically then, isometric contractions may be more advantageous to inducing potentiation than dynamic exercises.

Gullich and Schmidtbleicher (1996) analyzed the differences in the level of potentiation between the predominately slow-twitch soleus muscle and the gastrocnemius muscle, which is predominately fast-twitch, after MVCs consisting of unilateral five second isometric plantar flexion. Using a Kistler platform (Kistler Instrument Corporation, Novi, MI), the researchers measured explosive plantar flexion force after instructing each subject to exert force, as explosively and as fast as possible, onto the platform with the ball of the foot. Gullich and Schmidtbleicher
(1996) reported that the gastrocnemius exhibited a greater level of potentiation (32%) and demonstrated a longer lasting potentiated state (8.7 minutes), when compared to the soleus (20% potentiation, lasting 5.6 minutes). This finding shows that when choosing the potentiating exercise, one should take into account the muscles involved in the activity. Research suggests that the exercise should involve large muscle groups in order to enhance the amount of muscle activation leading to a potentiated state and subsequent explosive activity (Tillin & Bishop, 2009).

Though conditioning contractions involving lower body exercises are more common in the literature, upper body conditioning contractions have successfully demonstrated PAP (Baker, 2003; Esformes, Keenan, Moody, & Bampouras, 2011; Kilduff, et al., 2007). Using rugby league players who were experienced in power training, Baker (2003) examined the acute effect of alternating heavy and light resistances on power output during explosive bench press throws. Following a six-repetition set of bench presses with a resistance of 65% 1-RM, a significant increase (4.5%) in power output was observed. Similarly, the previously discussed study by Kilduff and colleagues (2007), reported a 5.3% increase in peak power output during a bench press throw following a preload stimulus of a 3-RM bench press. The research presented above suggests that PAP can be demonstrated in both the upper and lower extremities with an appropriately applied stimulus.

**Subsequent Activity.** Mechanical power is defined as the rate of force development over a particular distance, in a specific period of time, or force multiplied by velocity. Enhancement of mechanical power is the goal of using a potentiating activity to induce PAP; therefore, the potentiated activity should
incorporate explosive movement (Tillin & Bishop, 2009). Because RFD is typically amplified with PAP, a conditioning stimulus could increase the force and velocity of muscle contraction, consequently augmenting power and associated sports performance. Research indicates that both rapid repeated movements, such as sprinting (Bevan, Cunningham, Tooley, Owen, Cook, & Kilduff, 2010; Chatzopoulos, et al., 2007), and single-effort explosive activities, such as the CMJ (Esformes, Keenan, Moody, & Bampouras, 2011; Gullich & Schmidtleicher; 1996; Kilduff, et al., 2007; Rixon, Lamont, & Bemben, 2007; Weber, Brown, Coburn, & Zinder, 2008; Young, Jenner, & Griffiths, 1998) and bench press throw (Baker, 2003; Gullich and Schmidtleicher, 2006; Kilduff, et al., 2007), can be enhanced. Given the above results, a single-effort explosive movement, like a softball swing, may be enhanced after a conditioning contraction, as seen by an increase in subsequent bat velocity.

**Measurement**

**Measurement of PAP.** PAP has been measured a variety of ways in the research. In order to assess the degree of potentiation, researchers analyze an activity, or the outcomes of an activity, before and after a potentiating protocol. When analyzing high speed, short duration movements, PAP is usually quantified via rate of force development, power, jump height, peak force, peak torque, or ground reaction force. During continuous efforts, like sprinting, speed is often analyzed to evaluate the amount of potentiation. As PAP is largely dependent on the training status of the subjects, strength and power tests may also prove to be valuable during the interpretation of data.
Two measurements most commonly used to gauge potentiation are RFD (Esformes, Keenan, Moody, & Bampouras, 2011; Gilbert & Lees, 2005; Gullich & Schmidtleicher, 1996) and peak power output (PPO) (Esformes, Keenan, Moody, & Bampouras, 2011; Kilduff, et al., 2007; Rixon, Lamont, & Bemben, 2007). Though maximum force has been measured when authors are evaluating PAP, it has rarely shown any increases post-exercise (Gullich & Schmidtleicher, 1996; Rassier & MacIntosh, 2000).

In order to measure PPO, peak force, displacement, and RFD, Esformes and colleagues (2011) used a Ballistic Measurement System (BMS; Fitness Technology, Syke, South Australia, Australia). The BMS is a position transducer that produces variable-voltage output in relation to the displacement of a cable and then uses specialized software to convert the voltage data into displacement data. Kilduff, et al. (2007) also used this device to measure peak power output during a CMJ and a ballistic bench throw. In a different study, average power was assessed using a chronoscopic timing system, where two pairs of timing lights are positioned so that one pair measures the starting segment and the other pair measures the end segment (Brandenburg, 2005). Baker (2003) also measured power, but instead used the Plyometric Power System (PPS; Norsearch, Lismore, Australia). The PPS software was set up to calculate the average mechanical power output of the concentric phase of bench press throws based on the displacement of the barbell (D), time of displacement (T), and mass of the barbell (M) \((M \times G \times D/T = \text{power output in watts, where } G \text{ represents gravity})\). Peak power, however, may be more important to explosive sports performance, than average power. Countermovement
jump performance is often assessed using a force platform, such as the Kistler force platform (model 9281B, Kistler, Winterthur, Switzerland) mounted within the floor (Gilbert & Lees, 2007; McCann & Flanagan, 2010). Jump height, flight time, ground reaction force, and rate of force development can be assessed with a force plate (French, Kraemer, & Cooke, 2003; Gilbert & Lees, 2007; McCann & Flanagan, 2010; Weber, et al., 2008). A Vertec jump standard (Sports Imports, Columbus, Ohio), a non-electric standing scale, can also be used to evaluate jump height, but provides less insight than a force plate.

Chiu and colleagues (2003) analyzed force and power parameters during jump squat performance, before and after a heavy load squat, using a force platform and a position transducer. They then assessed each variable in terms of the percent potentiation in order to investigate the relative change in performance following the pre-load stimulus. To do this, they used the following equation:

\[
\text{Percent Potentiation} = \frac{\text{Potentiated variable}}{\text{Un-potentiated variable}} \times 100
\]

Percent potentiation equal to one-hundred percent indicates no potentiation, greater than one-hundred percent indicates the presence of PAP, and less than one-hundred percent suggests post-activation depression, or the presence of fatigue (Chiu, et al., 2003).

**Measurement of bat velocity.** Bat velocity has been measured using a variety of different methods in the literature. Reyes, et al. (2010) used high speed video cameras (filming two-hundred frames per second) to record each swing and analyzed the data using Streampix, 4.13.3 video program (Norpix, Montreal, Quebec, Canada). Similarly, Welch and colleagues (1995), Szymanski, et al., (2007a), and
Szymanski, et al., (2010) used motion analysis software to collect swing data with reflective markers and six cameras which, too, captured the swing at two-hundred frames per second. In addition, bat velocity has also been measured using an accelerometer attached to the bat and measured using two infrared photocell control boxes attached to a multifunction timer to record swing time (Reyes & Dolny, 2009). Wilson and colleagues (2012) used the SwingProPlus chronograph, a type of accelerometer, to measure peak bat velocity at peak acceleration, peak bat velocity of the swing, peak bat acceleration, and time to reach peak acceleration. This device consisted of a transceiver with a high-G accelerometer and a microcontroller positioned on the barrel of the bat. During each swing, the microcontroller recorded data at ten-millisecond intervals for four-hundred milliseconds (Wilson, et al., 2012). Hitters produce maximum swing speed just prior to ball contact (Welch, et al., 1995).

**Measurement of 1-RM strength.** The most commonly used method for assessing muscular strength is the one repetition maximum (1-RM) (Beachle & Earle, 2008). 1-RM testing requires an individual to lift as much as possible once, through a full range of motion (Beachle & Earle, 2008). Although this type of assessment is considered the most accurate way to determine maximal dynamic strength, there are some fundamental complications associated with it (Mayhew, Johnson, LaMonte, Lauber, & Kemmler, 2008). One particular problem is that the high load can increase the risk for injury (Mayhew, et al., 2008). When testing athletes during the competitive season, injury prevention is of primary concern, and therefore alternative approaches assessing 1-RM strength should be considered.
Another method to determine maximal strength is to estimate the 1-RM by using repetitions performed to the point of temporary muscle failure, which is termed repetitions to fatigue (RTF) (Beachle & Earle, 2008; Mayhew, et al., 2008). Using this method, the subject would select a load that was believed to be less than their 1-RM and perform as many consecutive repetitions as possible. The load or RTF would then be applied to any of a number of available prediction equations to estimate the individual's 1-RM value (Mayhew, et al., 2008). Most of the current equations function best when using a load that will produce a range of two to ten repetitions (Beachle & Earle, 2008). Although many of these equations are reasonably accurate and precise, some do not provide information on the population from which they were developed (Mayhew, et al., 2008). This is a concern for the use of these prediction equations because the age, gender, and training status of the individuals may affect the accuracy and precision of the 1-RM estimation. A study analyzing the accuracy of prediction equations for determining 1-RM bench press in college aged women reported that of fourteen prediction equations, only three equations produced predicted 1-RM values that were significantly different from the actual 1-RM (Mayhew, et al., 2008). The most accurate equation proved to be one by O’Connor, Simmons, and O’Shea (1989). This prediction equation \(1\text{-RM} = (0.025 \times [\text{rep wt.} \times \text{RTF}]) + \text{rep wt.}\) was further substantiated by Reynolds, Gordon, and Robergs (2006), who reported that of eight established equations found in the literature, the equation created by O’Connor and colleagues (1989) was the most accurate in predicting leg press and bench press 1-RM strength from multiple repetition testing \(r = 0.99\).
Summary

It is evident in the research that the balance between potentiation and fatigue determines if the subsequent performance is augmented, reduced, or unchanged (Tillin & Bishop, 2009). In order to effectively utilize PAP, recovery duration must be long enough for fatigue to dissipate, but not so long that potentiation is removed; this window of opportunity may only exist in trained individuals. When selecting optimum recovery, one must take into account the physical characteristics of the individual attempting to exploit this phenomenon, the intensity and volume of the conditioning contraction, the type of the potentiating and potentiated activity, and the muscles involved in both activities. It is clear, though, that if implemented properly, PAP can augment muscle function. The research suggests the practical significance of PAP in the preparation for athletic competition and its profound implications regarding potential warm-up strategies employed prior to explosive activity.

Nearly all movements performed in softball, especially hitting, involve explosive whole-body drive and rotation. In order to enhance hitting performance, players must improve the way they use their body as a kinetic link and find a way to maximize rate of force development to increase the power delivered from their body, to the ball. Although research has provided evidence for increased muscular performance following the facilitation of heavy resistance exercise, this has not been clearly established for use prior to measuring bat velocity. Commonly used warm-up implements in baseball and softball seem to have no consistently positive impact on the swing, showing a clear need for a warm-up protocol advantageous to
subsequent bat velocity. Research suggests that the dynamic nature of frequently utilized warm-up routines may be responsible for the lack of potentiation seen following the use of a weighted implement. A high intensity isometric conditioning contraction, however, may allow for potentiation without disrupting the hitter’s coordination, timing, technique, and kinetic chain. Using the information presented in the research, there is a clear possibility for the development of a potentiating procedure that can significantly increase at-bat bat velocity in well trained softball players. More research is needed in this area.
Chapter III

Methods and Procedures

Introduction

This study tested the hypothesis that an isometric conditioning contraction warm-up protocol would result in increased bat velocity in experienced female softball players. Post-isometric warm-up bat velocity results were compared to each subjects’ baseline bat velocity, as subjects served as their own controls. Descriptions of the study population, design, warm-up protocol, and data collection process are included in this chapter.

Description of study population

The sample used in this study consisted of female softball players between the ages of sixteen and twenty-five, who had at least five years of experience playing competitive fastpitch softball. Both right and left handed hitters were used for analysis. All subjects participated in softball year-around and were instructed to continue their normal training (including resistance training, conditioning, and sports specific practice), except on testing days. As the results of this study would serve the athletes best while in season, testing was conducted in early spring.

Design of study

The study was a single group repeated measures design to analyze the effect of a potentiating warm-up on maximal horizontal bat velocity. Twenty-eight subjects were selected from volunteers to participate in the study. Pre and post-conditioning contraction data of maximal horizontal bat velocity results were compared. This study also employed a correlational test to compare baseline
measures of absolute strength (ABS) and relative strength (REL) to the degree of potentiation or fatigue experience by each subject as represented by their bat velocity change scores.

**Data collection procedures**

The Human Subjects Committee at Western Washington University approved this study (Appendix A). Prior to contacting volunteers to participate, permission was granted from the coaches of the players (Appendix B). The risks and benefits of participation in this study were explained to each subject. All volunteers and their parent(s) or guardian(s) (if the subject was under the age of eighteen) completed a written informed consent, minor assent (if under 18), and a hold harmless form (Appendix C) before being permitted to participate. All subjects and their parent(s) or guardian(s) (if the subject was under the age of eighteen) completed a permission to videotape form (Appendix D) as well.

**Instrumentation.** The isometric potentiating protocol utilized a device designed by the author and engineered by Scientific Technical Services at Western Washington University. The device consisted of a softball bat handle, wrapped with bat grip tape, attached to a chain, 102 centimeters in length, which in turn attached to a height adjustable fitting on a wall. Horizontal bat velocity was measured during each swing trial using a Casio (Casio Computer Co., Ltd., Tokyo, Japan) high speed video camera, filming at four-hundred-and-twenty frames per second. The camera was positioned on a tripod, perpendicular to the hitting zone, in the frontal plane. A meter stick aligned in the field of view of the video camera served as a distance reference, which was used to calculate bat displacement per video frame. Bright
reflective tape was connected to the barrel of a Louisville Slugger Catalyst fastpitch bat (Louisville Slugger, Louisville, KY) of standard length, 83.8 centimeters (thirty-three inches), and weight, twenty-three ounces. This tape served as a marker during filming in order to make the manual digitization consistent throughout the trials. As recommended by the research (Bassett, et al., 2011; Szymanski, et. al., 2011; Welch, 1995), bat velocity was measured immediately prior to ball contact. The distance that the reflective marker on the bat barrel traveled in each frame of the high-speed video recording was later used to determine bat velocity in meters per second. The video position data was analyzed using MaxTRAQ motion analysis software (Innovision Systems, Inc., Columbiaville, MI) and later exported into Excel® 2010 (Microsoft Corp., Bellevue, WA) for further analysis.

**Measurement techniques and testing procedures.** Data collection took place at Western Washington University in the Parberry Strength Center and the Biomechanics Laboratory. Two separate sessions were implemented, the first to administer the potentiating warm-up protocol and measure bat velocity, and the second to conduct maximum strength testing. Each subject’s height and weight was taken during the first meeting. Each subject was questioned regarding any injury or impairment they may have had and asked to report how many years they had participated in the sport. Inclusion for this study demanded that subjects be free of any musculoskeletal or neurological impairment or injury. Subjects abstained from any heavy resistance exercise and creatine supplementation 48 hours prior to both testing sessions. Subjects were also to refrain from consuming alcohol (24 hours) and caffeine (8 hours) before the experiments.
During the first session, subjects began a standardized warm-up consisting of general, dynamic, and specific phases. The general warm-up consisted of jogging on a treadmill for two minutes at six miles per hour. Immediately after the general warm-up, subjects completed a dynamic warm-up which followed their typical pre-game routine. This consisted of thirty seconds of walking arm-circles and cross-body shoulder slaps, as well as five repetitions on each leg of a lunge to torso twist, walking knee hugs, walking quad stretches, and an inverted hamstring stretch. Monster walks, side-shuffles, and high knees were also performed for a distance of ten-yards per exercise. After a four minute rest period, the subjects completed a specific warm up consisting of one set of five dry swings, increasing in intensity, with the testing bat. The dry swings were followed by one set of five warm-up swings hitting a teed ball into a net. The last three swings were to be performed at maximal effort. The tee was positioned down the center and at the forward edge of home plate. Tee height was set even with each hitter’s umbilicus during the blocking phase of the swing. In order to increase the consistency of the swings throughout the swing trials, athletic tape was placed on the ground marking comfortable foot placement for the subject during the teed warm-up swings. The balls used in testing were twelve inch, game-ball yellow, Lite-Flite® softballs (Jugs Sports, Tualatin, OR). During a two minute recovery period, the high speed camera was set into position to fully capture the subject’s swing. After the two minutes, subjects were told to assume a stance and swing as if they were in a game situation. Rest periods of twenty-seconds were given between swings to recover and simulated the time taken between pitches in a game situation. Given that horizontal velocity of the bat
head was being measured, data may have been affected by different aspects of the swing, such as the angle and location of bat-ball impact. In order to account for this, subjects were asked to drive the ball on a line up the middle towards what would be center field. A red square (30 cm x 30 cm) was placed in the center of the net as a visual target for all subjects to hit. The researcher, who had intercollegiate softball experience, made a qualitative judgment as to whether or not each swing met the criteria for accurate measurement. Three maximal swings, which met the requirements, were recorded. The average horizontal bat velocity of the three was used for analysis and considered to be the subject’s baseline bat velocity.

Once baseline bat velocity was established, subjects were given ten minutes to recover. During this time, clear and like instructions regarding the phase specific isometric conditioning contraction were given to each subject (see script in Appendix E). The experimental potentiating isometric warm-up consisted of each subject pulling against a bat handle connected to a chain attached to a wall. Subjects were instructed to slowly progress through their swing motion, initiated in the legs, and stop in the early swing phase, approaching “slot” position. While in this position, the chain (connected to the bat handle and the wall) was stretched tight, and any further movement forward in the swing was prohibited by the chain. Subjects were instructed to maximally contract muscles as if attempting to break free and finish their swing. As previously discussed, specific trailing leg muscles, trunk muscles, and lead arm muscles should be active during the early swing phase, as the hitter approaches the “slot” position (Shaffer, Jobe, Pink, & Perry, 1993). To ensure that each subject was properly activating the muscles involved in this position, the
researcher performed manual muscle tests on the trail leg biceps femoris and
gluteus maximums, the abdominal obliques, and the lead arm posterior deltoid and
triceps during each maximal voluntary contraction (MVC). The researcher also made
a qualitative judgment to ensure that each subject was in fact in the early swing
phase position. The main criterion for this was that the elbow and knee of the
trailing arm and leg were aligned vertically and that the hips were neither fully
closed nor fully open. Three maximal effort isometric contractions were sustained in
this position for five seconds. Each isometric MVC was separated by thirty seconds
of recovery.

Upon completion of the potentiating protocol, each subject returned to the
batter’s box and was instructed to swing the bat maximally at the teed softballs, just
as they had done previously. Trials were taken at one minute, two minutes, four
minutes, six minutes, eight minutes, ten minutes, and twelve minutes post-exercise.
All trials were recorded the high speed video camera. Each trial was saved with a
subject and trial number. All trials were imported into MaxTRAQ motion analysis
software (Innovision Systems, Inc., Columbiaville, MI) and were manually digitized
by the researcher. Each video was cut down to the range of interest, which began
just before each subject reached slot position and ended just after ball contact. The
sweet spot of the bat, identified by the bright reflective marker, was digitized for
every frame in the range of interest. Once digitization was complete, the position
data was exported from MaxTRAQ into Excel® 2010 (Microsoft Corp., Bellevue,
WA). Bat velocity, in meters per second, was calculated from the position data and
the frame rate, using the first central difference method. Maximal horizontal bat velocity was then established by finding the maximum value.

During the second session, subjects began a standardized warm-up consisting of general, dynamic, and specific phases. The general warm-up consisted of jogging on a treadmill for three minutes at six miles per hour. A dynamic warm-up immediately followed, consisting of five repetitions on each leg of a lunge to knee hug, lunge to torso twist, walking quad stretch, and an inverted hamstring stretch. Additionally, five repetitions of wall slides and cross-body shoulder slaps were performed. Following this, the subjects completed a specific warm up of five body weight squats followed by five push-ups. After the warm up the subjects were given a four minute recovery period before strength testing commenced.

Injury prevention was a primary concern of the researcher, the coaches, and the athletes involved in this study, especially since the athletes were starting their competitive season. Therefore, predicted one repetition maximum (1-RM) using multiple repetition (repetitions to fatigue) testing was selected for this study. Given the reliability and accuracy of the equation created by O’Connor and colleagues (1989), this equation (1-RM = (0.025 x [rep wt. x RTF]) + rep wt.) was chosen to predict 1-RM strength for the bench press and back squat for the current study. Though all subjects had previous weight training experience, prior to testing, proper technique for the bench press and back squat was explained to the athletes according to the standards of the National Strength and Conditioning Association.

Following the previously described warm-up, the athletes completed ten repetitions at 50% of their self-estimated 1-RM. After a four minute rest period, a
second set was completed and consisted of five repetitions at 75% of the subjects’ self-estimated 1-RM. Following another four minute rest period, the weight was increased by 10-15% and each subject was asked to lift the weight for as many repetitions as possible until failure. Failure was defined as the inability of the subject to attain proper depth during the eccentric (down) phase and full extension during the concentric (up) phase of the exercises. To establish the proper depth of the back squat, subjects were required to touch an elastic band, during the down phase of the squat, set at the height of their tibial tuberosity while standing. Appropriate form and depth of both exercises was evaluated by a certified strength and conditioning specialist. Each subject’s load and number of repetitions to failure were recorded and later put into the prediction equation to estimate 1-RM strength for each exercise. Subjects were given verbal encouragement during all testing sessions. Once the estimated 1-RM, or absolute strength (ABS), values were calculated for each subject, relative strength (REL) was found by taking the ratio between each subject’s strength and weight (ABS strength (kg) / body mass (kg)).

**Statistical Analysis**

Means and standard deviations were calculated for baseline bat velocity and bat velocity at each of the seven time points following the potentiating warm-up protocol. Statistical analysis was carried out using a one-way repeated measures analysis of variance (ANOVA) (baseline bat velocity vs. bat velocity at 1, 2, 4, 6, 8, 10, and 12 minutes post- isometric warm-up) with SPSS (Version 12, Chicago, IL). Alpha level was set $p < 0.05$. In the event of a significant effect, post-hoc testing using pairwise comparisons, with a Bonferroni correction, was conducted. A
polynomial trend analysis was also completed, as well as tests for effect size ($\omega^2 > 0.15$ was large, $\omega^2 > 0.06$ was medium, $\omega^2 > 0.01$ was small). Change scores were calculated for each time point following the potentiating warm-up protocol. To do this, the following equation was used: \( \text{change score} = \text{potentiased variable} - \text{un-potentiated variable}. \) The post-isometric-warm-up bat velocity represented the potentiated variable and the baseline bat velocity represented the un-potentiated variable. Percent change from baseline was also calculated. A Pearson product moment correlation coefficient was calculated to assess the relationship between baseline measures of absolute and relative strength and the amount of potentiation that occurred.
Chapter IV
Results and Discussion

Introduction

This study tested the hypothesis that a specific isometric warm-up protocol would result in increased bat velocity in experienced high school and collegiate softball players. Maximal horizontal bat velocity was measured before and after the high intensity isometric potentiating warm-up. Post-isometric warm-up bat velocity results were compared to each subject’s baseline bat velocity, as subjects served as their own controls. Subjects were tested at one, two, four, six, eight, ten, and twelve minutes following the warm-up protocol, as the time frame of potentiation, if any, had not been identified. A correlation was also run to compare absolute strength and relative strength to the degree of potentiation experienced by each subject, as represented by their bat velocity change scores.

Subject characteristics

Twenty-eight (n=28) female subjects, aged 16 to 25 (20 ± 2.6) years old, volunteered for this study. All subjects were healthy, competitive fastpitch softball players with an average of 11.5 (±3.2) years of experience. Means and standard deviations (±SD) for subject characteristics, including absolute strength (ABS) and relative strength (REL), are provided in Table 1.
Table 1.

*Subject Characteristics*

| Subject Age (years)          | Mean | ±SD  |
|-------------------------------|------|------|
| Subject Experience (years)    | 11.5 | 3.2  |
| Subject Height (cm)           | 162  | 29   |
| Subject Weight (kg)           | 69.19| 11.36|
| ABS (1-RM Bench Press) (kg)   | 43.44| 6.95 |
| ABS (1-RM Back Squat) (kg)    | 75.18| 11.71|
| REL (ABS Bench Press/BW) (%)  | 0.63 | 0.09 |
| REL (ABS Back Squat/BW) (%)   | 1.10 | 0.17 |
| Baseline Bat Velocity (m/s)   | 25.74| 2.65 |

**Results**

The results support the experimental hypothesis demonstrating a significant effect of the isometric potentiating warm-up protocol on bat velocity over time ($F[7,198] = 4.49$, $p < 0.001$). The effect size is medium ($\omega^2 = 0.143$). Post-hoc testing revealed that bat velocity is significantly higher six minutes after the potentiating protocol when compared to baseline bat velocity ($p = 0.006$) and bat velocity at one minute after the potentiating protocol ($p = 0.001$). The results also indicate that there is a significant quadratic trend, with bat velocity peaking at six minutes and subsequently decreasing ($F[1, 27] = 8.79$, $p = 0.006$). The effect size for this trend is large ($\omega^2 = 0.246$).
Table 2.
Mean, standard deviation, and change score data for maximal horizontal bat velocity during the pre- and post-warm-up swing trials.

| Time        | Bat Velocity (m/s) | ±SD  | Change in Bat Velocity from Baseline (m/s) | %   |
|-------------|--------------------|------|-------------------------------------------|-----|
| Baseline    | 25.74              | 2.65 | N/A                                      | N/A |
| Post 1 min  | 25.46              | 3.05 | -0.28                                    | -1.09 |
| Post 2 min  | 25.98              | 2.99 | 0.24                                     | 0.94 |
| Post 4 min  | 26.06              | 3.00 | 0.32                                     | 1.26 |
| Post 6 min  | 27.01*†            | 2.97 | 1.27                                     | 4.93 |
| Post 8 min  | 26.54              | 3.05 | 0.80                                     | 3.12 |
| Post 10 min | 26.31              | 2.65 | 0.57                                     | 2.23 |
| Post 12 min | 26.12              | 3.11 | 0.48                                     | 1.49 |

Notes: Percent change (%) represents the change from baseline bat velocity (25.74 ± 2.65 m/s). * Indicates the results are significantly different from baseline bat velocity (p < 0.05). † Indicates that the results are significantly different from 1 minute post-warm-up bat velocity (p < 0.05).

On average, subjects exhibited potentiation at all time points following the isometric warm-up, with the exception of the one minute swing trial. However, maximal horizontal bat velocity was only significantly potentiated six-minutes after the high intensity isometric potentiating warm-up, eliciting an average increase in bat velocity of 1.27 m/s (2.84 mph) when compared to baseline bat velocity (Table 1). As seen in Figures 1 and 2, bat velocity decreased one minute following the isometric warm-up (-0.28 m/s, -0.63 mph, -1.09%), and then increased above baseline at two minutes (+0.24 m/s, +0.54 mph, +0.94%). Bat velocity continued to increase until six minutes following the potentiating warm-up, where it peaked at an average of 27.01 m/s (60.41 mph); significantly greater than average baseline bat velocity (+1.27 m/s, +2.84 mph, +4.93%). At eight minutes, bat velocity decreased from an average of 27.01 m/s (60.41 mph) at six minutes to an average of 26.54 m/s (59.36 mph), but still remained 3.12% above baseline bat velocity. Between eight
and twelve minutes, bat velocity continued to gradually decrease. At twelve minutes following the potentiating warm-up, bat velocity remained elevated 0.48 m/s (1.06 mph) and 1.49% above baseline bat velocity. At six minutes after the high intensity isometric warm-up, bat velocity was significantly higher than both baseline bat velocity and bat velocity at 1-minute post warm-up (Figure 1). The significant quadratic trend, peaking at six minutes, is visible in Figures 1 and 2.

**Figure 1.** A graphical comparison of average bat velocity during the pre- and post-warm-up swing trials. Error bars are set at mean standard deviation. * Indicates the results are significantly different from baseline bat velocity (p < 0.05). † Indicates that the results are significantly different from 1 minute post-warm-up bat velocity (p < 0.05).
Figure 2. A graphical comparison of average change in bat velocity between baseline and the post-warm-up swing trials.

The results also revealed no correlation between the degree of potentiation that occurred after six minutes of recovery and ABS upper body ($r = 0.025, p = 0.899$) and lower body ($r = 0.036, p = 0.841$) or REL upper body ($r = -0.097, p = 0.628$) and lower body ($r = -0.071, p = 0.722$) strength.

**Discussion**

The purpose of this study was to examine the acute effect of a high-intensity isometric potentiating warm-up on subsequent maximal horizontal bat velocity in experienced female softball players. The isometric potentiating warm-up consisted of three sets of five-second maximal voluntary contractions held in the early swing phase, pulling against an immovable device created by the researcher. The warm-up was designed to acutely enhance muscle performance by inducing PAP, ultimately causing an increase in maximal horizontal bat velocity. Because optimal recovery duration following a potentiating warm-up can be highly variable (Gullich
& Schmidtbleicher, 1996; Jensen & Ebben, 2003; Kilduff, et al., 2007; Wilson, et al., 2012), swing trials were conducted at pre-determined rest intervals in order to identify the recovery time which may have allowed for maximal possible benefits.

The results indicate that the phase specific isometric warm-up elicited increased bat velocity above baseline at two, four, six, eight, ten, and twelve minutes following the conditioning contractions. Statistical analysis showed that maximal horizontal bat velocity was significantly enhanced six minutes post-warm-up, showing a 1.27 m/s (2.84 mph) and 4.93% increase in bat velocity, when compared to baseline measures. The positive effect of the potentiating warm-up protocol is similar to what has been reported in the literature regarding PAP and explosive performance.

Rixon and colleagues (2007), who also employed an isometric warm-up, found that the conditioning contractions evoked a 2.2% increase in jump height and an 8.4% increase in peak power output three minutes following the warm-up. Though not isometric, Young, Jenner, and Griffiths (1998) reported that a single set of squats performed with a 5-RM load significantly increased athletes’ jump height by 2.6%, after a four minute recovery. Upper body conditioning contractions have also successfully demonstrated PAP (Baker, 2003; Esformes, Keenan, Moody, & Bampouras, 2011; Kilduff, et al., 2007). Baker (2003) found that a six-repetition set of bench presses with a resistance of 65% 1-RM can elicit a 4.5% increase in power output during explosive bench press throws, after a three minute recovery. Kilduff and colleagues (2007), who analyzed both upper and lower body PAP, reported a 5.3% increase in peak power output during a bench press throw, twelve minutes
after a preload stimulus of a 3-RM bench press, and a 6.8% increase in peak power output during a CMJ eight minutes after a 3-RM back squat. Though the studies presented above did not investigate the same potentiated activity, the results are similar to the findings of the current investigation, showing a nearly 5% increase in explosive power performance following a high intensity pre-load stimulus.

More specifically related to the current study, Wilson and colleagues (2012) examined the effects of various warm-up devices and rest period lengths (one, two, four, and eight minutes) on bat velocity. The researchers, who tested collegiate baseball players, found no significant effects on bat velocity from any of the weighted warm-up devices and so pooled the peak value data together when looking at effects of recovery time. The analysis revealed that peak bat velocity increased significantly, from a baseline average of 37.29 m/s to 38.75 m/s, after a rest period of two minutes. Bat velocity increased again at four minutes (39.25 m/s) and peaked at eight minutes (40 m/s). Wilson and colleagues (2012) did not test bat velocity at six minutes, where potentiation could have been greatest, according to the present results. The higher bat velocities presented by Wilson et al. (2012) are likely due to the greater body mass (88.3 ± 15.8 kg versus 69.19 ± 11.36 kg in the current study). Because the subjects in the study by Wilson, et al. were males, the muscle mass of the baseball players are presumably greater when compared to the softball players used in the current study.

In a similar study, Higuchi and colleagues (2013) examined the acute change in bat velocity following three types of warm-up procedures, using NCAA Division I collegiate baseball players. The three types of pre-batting warm-ups consisted of (1)
five standard bat swings, (2) five weighted bat swings, and (3) four sets of five-
second maximal voluntary isometric contractions mimicking the bat swing
movement pattern (Higuchi, Nagami, Mizuguchi, & Anderson, 2013). The results
indicated that after one minute of recovery the standard bat warm-up did not
significantly change bat velocity (-0.33 m/s) and the weighted bat warm-up
significantly decreased bat velocity (-0.89 m/s), however, the maximal isometric
warm-up significantly increased bat velocity (+0.39 m/s) (Higuchi, Nagami,
Mizuguchi, & Anderson, 2013). Higuchi and colleagues did not test bat velocity at
any other time point.

Unlike the findings of Higuchi et al., the current study showed that bat
velocity decreased (-0.28 m/s) after one minute of recovery. However, a 0.34 m/s
increase in bat velocity, similar to what Higuchi and colleagues reported, was found
four minutes after the isometric warm-up protocol. The difference in the window of
potentiation may be due to the difference in muscle mass between the Division I
baseball players and the high school and collegiate softball players. The
conditioning contractions may more easily deplete the muscle phosphocreatine
(PCr) stores and consequently induce greater fatigue in the softball players, when
compared to high level baseball players. Therefore, in softball players, the window
for potentiation may occur later, after fatigue subsides. However, it is important to
note that some fatigue is expected and that, on average, the experienced female
softball players only exhibited one minute of decreased performance following the
isometric-warm-up. High level baseball players may have a greater capacity for
potentiation, hypothetically making the isometric warm-up more effective.
Performance following a potentiating protocol depends on the interplay between fatigue, which impairs performance, and potentiation, which enhances performance (Rassier & MacIntosh, 2000). The depletion of PCr may be responsible for the fatigue experienced following a conditioning contraction (Hirvonen, Nummela, Rusko, Rehunen, & Härkönen, 1992). In order for potentiating warm-up protocol to be effective in acutely enhancing muscle performance, the phosphorylation of myosin regulatory light chains (RLC) must be able to outlast the repletion of phosphagen stores in the muscle (Tillin & Bishop, 2009). Re-synthesis of PCr stores usually occurs between four and eight minutes post-exercise (Behm, et al., 2005; Harris, et al., 1976), while the time-course for the rate of dephosphorylation of myosin RLCs, via the slow activity of myosin light chain phosphatase, seems to be around twelve minutes (Moore & Stull, 1984). With this information, a window of potentiation for optimal performance may exist between four and twelve minutes of recovery. The time course of potentiation found in this study closely resembles what is presented above, providing a scientific explanation for the quadratic trend; with performance increasing after two minutes of recovery, peaking at six minutes, and decreasing as twelve minutes of recovery approaches.

The literature, as well as the results presented in this study, shows a varying window of potentiation from two to twelve minutes, dependent on the potentiating activity, the potentiated activity, and, most importantly, the individual. Though a significant quadratic trend was observed in the current study, response to the potentiating stimulus may be specific to subject characteristics. Research suggests that PAP is primarily exhibited in well trained individuals (Baker, 2003;
Chatzopoulos, et al., 2007; Kilduff, et al., 2007; Weber, Brown, Coburn, & Zinder, 2008; Young, Jenner, & Griffiths, 1998) and that absolute strength is correlated to the percent performance enhancement (Kilduff, et al., 2007). Consequently, strength testing was analyzed in conjunction with change in bat velocity.

In contrast with the research, no correlation was found between upper or lower body absolute or relative strength and the degree of potentiation in the current investigation. This relationship, or lack thereof, could be due to various reasons. The subjects used in the current study are similarly trained. All of the softball players who participated had weight training experience and train year-around for their sport. Though slightly different, they participate in comparable exercise regimens and demonstrated similar strength levels during testing. The subjects involved in this study also demonstrated very similar baseline bat velocities (25.74 ± SD 2.65 m/s). Because of this likeness in training status and the baseline measures of strength and bat velocity, it may be that as a group, they would potentiate similarly. Another reason for the lack of correlation may be that the swing is a complex whole-body movement which relies heavily on the ability to efficiently transfer energy up the kinetic chain. Bench press or back squat strength may not be critical or strongly related to how PAP alters maximal bat velocity.

Based on the literature and the findings presented here, a high intensity isometric potentiating warm-up may enhance maximal horizontal bat velocity in female softball players via the mechanism(s) of PAP. Furthermore, 1-RM strength may not be a strong predictor of swing potentiation in trained high school and collegiate female athletes.
Summary

According to the data, maximal horizontal bat velocity can be significantly augmented six minutes after a phase-specific high intensity isometric warm-up protocol, consisting of three 5-second isometric contractions at maximal effort, in experienced high school and collegiate softball players. Bat velocity was elevated above baseline at two (+0.94%), four (+1.26%), six (+4.93%), eight (+3.12%), ten (+2.23%), and twelve (+1.49%) minutes following the conditioning contractions, displaying a window of potentiation between two and twelve minutes of recovery. Optimal recovery time may shift, depending on the individual. A significant quadratic trend, peaking at six minutes, indicates that the subjects involved in this study followed the same general pattern, increasing and then decreasing their bat velocity over time. The positive effect of the potentiating warm-up protocol, as well as the time frame of potentiation, is similar to what has been reported in the literature regarding PAP and explosive performance. The similarity between this study and the literature may be due to the close adherence to the load, volume, and recovery time, while the difference in percent potentiation may be due to the differences in the potentiated activity, as well as the sex and level of training of the subjects. The studies reporting 5-10% increases in peak power output tested activities such as the countermovement jump and explosive bench press throw, and used elite male athletes, such as professional rugby players (Kilduff, et al., 2007; Rassier & MacIntosh, 2000). Such well-trained individuals may have a greater capacity for potentiation (Kilduff, et al., 2007; Rassier & MacIntosh, 2000; Rixon, Lamont, & Bemben, 2007).
Chapter V
Summary, Conclusions, and Recommendations

Summary

The body of literature regarding PAP has expanded in recent years as a viable method to increase power (Esformes, Keenan, Moody, & Bampouras, 2011; Kilduff, et al., 2007; Rixon, Lamont, & Bemben, 2007) and rate of force development (RFD) in athletes (Esformes, Keenan, Moody, & Bampouras, 2011; Gilbert & Lees, 2005; Gullich & Schmidtbleicher, 1996). It is clear that the balance between potentiation and fatigue determines if the subsequent performance is augmented, reduced, or unchanged (Tillin & Bishop, 2009). In order to effectively utilize PAP, recovery duration must be long enough for fatigue to dissipate, but not so long that potentiation is removed. This window of opportunity may only exist in trained individuals and may vary with level of training. When selecting optimum recovery, one must take into account the physical characteristics of the individual attempting to exploit this phenomenon, the intensity and volume of the conditioning contraction, as well as the type of the potentiating and potentiated activity. It is evident that if implemented properly, PAP can augment muscle function. This improvement suggests the practical significance of PAP in preparation for athletic competition.

Due to having an established batting order, offensive performance in baseball and softball presents a unique platform on which to take advantage of the PAP phenomenon. Hitting is a powerful whole body movement and bat velocity has been
deemed crucial for offensive success (Reyes, Dickin, Dolny, & Crusat, 2010; Szymanski, et al., 2012). Increasing maximal horizontal bat velocity can increase batted ball distance and velocity, extend decision-making time, and improve the likelihood of making solid contact with the ball on the sweet spot of the bat (DeRenne, Ho, Hetzler, & Chai, 1992; Katsumata, 2007; Szymanski, et al., 2007a). Weighted warm up devices are commonly used in baseball and softball to prepare athletes for performance. However, dynamic weighted bat warm-ups have been repeatedly shown to have no effect (Reyes & Dolny, 2009; Szymanski, et al., 2011; Szymanski, et al., 2012), or a negative effect (DeRenne, Ho, Hetzler, & Chai, 1992; Southard & Groomer, 2003) on subsequent bat velocity. A specific isometric warm-up may be a positive alternative to the frequently used dynamic weighted bat warm-up.

**Conclusions**

The current experimental hypothesis was confirmed, in that the potentiating warm-up, utilizing high-intensity isometric contractions, elicited a significant increase in bat velocity when compared to subjects’ established baseline bat velocity. Subjects were tested at one, two, four, six, eight, ten, and twelve minutes following the potentiating protocol. On average, subjects exhibited potentiation at all time points, with the exception of the one minute swing trial. The greatest amount of potentiation (+1.27 m/s, +2.84 mph, +4.93%) was realized six minutes after the high intensity isometric potentiating warm-up. Therefore, a high intensity isometric warm-up may be useful in the acute enhancement of maximal horizontal bat velocity.
Recommendations

Future Research. As the mechanism(s) regulating PAP have not yet been fully elucidated, more research is needed in this area. The inconsistent results of past research appear to be due to the complex interaction of several factors that determine the degree to which the mechanism(s) of PAP and fatigue are affected. A major flaw in the research is that no well-designed studies have established a time course of changes in TP and RP following a voluntary conditioning activity in humans, while concurrently relating these changes to subsequent strength and power performance. A method by which to ameliorate this issue would be to develop an experimental protocol that gives valid measures of force production with concurrent measures of neuromuscular output. Understanding the primary mechanism(s) mediating PAP would have profound implications on performance enhancement, in that it may promote further development of strategies to optimize warm-up and training programs.

Repeating the high intensity isometric potentiating warm-up presented in this study with professional baseball players is also recommended. A study on NCAA Division I baseball players by Higuchi and colleagues (2013) also implemented an isometric warm-up, but only tested bat velocity after one minute of recovery. After one minute of rest, Higuchi and colleagues (2013) reported that bat velocity was 0.39 m/s (1.8 mph) faster than baseline bat velocity; similar to what was found after four minutes of recovery in the present study. Because the literature on PAP typically shows maximal benefits anywhere between two and twelve minutes, it would be interesting to see how the results presented in this study, on
experienced high school and collegiate softball players, compared to the results of experienced baseball players, who may retain a wider window of potentiation.

As the continuous testing of the potentiated activity is a limitation of this study, investigating the current potentiating protocol without swing trials taking place every two minutes might allow for a more accurate indication of the time point in which potentiation is greatest. Because the subjects involved in the current study completed three swing trials between the conclusion of the isometric warm-up and the six-minute swing trial, the time point exhibiting the greatest amount of potentiation may not be six-minutes post-warm-up. Additional testing is needed to investigate this possibility.

Additionally, implementing the warm-up protocol presented in this study as a training regimen could promote a chronic increase in bat velocity. Strength and conditioning research often promotes specificity training. Using the device created by the researcher, performing maximal isometric contractions, while in the early swing phase, as a part of a weekly training program, may increase the strength and power output of the muscles involved in the swing and could improve force production in the early swing phase. Such a training program could also promote a larger window of potentiation for performance. A longitudinal training study may support this possibility.

**Practical Applications.** The ability of a baseball or softball player to increase maximal horizontal bat velocity provides him/her more time to observe the oncoming pitch, allowing for a more accurate evaluation of the speed, location,
and movement of the ball, increasing the hitter’s chances of making solid contact (Reyes, Dickin, Dolny, & Crusat, 2010). Increased bat velocity also facilitates increased batted ball distance and velocity (DeRenne, Ho, Hetzler, & Chai, 1992; Szymanski, et al., 2007a). According to previous research, the widely used weighted bat warm-up produces no effect or a negative effect on post–warm-up bat velocity (DeRenne, Ho, Hetzler, & Chai, 1992; Reyes & Dolny, 2009; Southard & Groomer, 2003; Szymanski, et al., 2011; Szymanski, et al., 2012). Furthermore, the after effects of swinging a weighted bat with an increased moment of inertia can not only change a batter’s perception of the swing (Otsuji, Abe, & Kinoshita, 2002), but also the batter’s swing pattern (Liu, Liu, Kao, & Shiang, 2011; Southard & Groomer, 2003). Instead, using a high intensity isometric pre-batting warm-up protocol can be a positive alternative to optimally increase at-bat bat velocity.

Based on the findings in this study, the implementation of a warm-up utilizing multiple isometric conditioning contractions can be an effective way for competitive female softball players to increase their bat velocity. The isometric conditioning contraction may increase the power production and rate of force development in the position of the early swing phase. The positive effect of the high intensity isometric warm-up can be explained by the PAP phenomenon.

The device created by the researcher may be beneficial to hitters during competition. Following the protocol presented in this study, warming up with the device while waiting for a turn at bat may facilitate greater at-bat bat velocity. Though it may prove difficult to complete the warm-up protocol exactly six-minutes
prior to an at-bat, the results show that bat velocity, on average, remained elevated above baseline levels for ten minutes (two to twelve minutes following the warm-up protocol) and possibly longer. Therefore, the benefits may exist so long as the warm-up is completed at least two minutes prior to the at-bat. Because of the varying response to the potentiating stimulus, it would be important to assess when bat velocity peaks following the warm-up for each individual player, prior to implementing the warm-up during competition. As increasing bat velocity could also affect proper timing, it is suggested that players use the device in practice in order to learn how to adjust their timing during a game.

The effect of isometric exercise on PAP, established in multiple studies, has profound implications for trainers, coaches, athletes, and fitness enthusiasts. Performing maximal or near maximal voluntary contractions, pushing or pulling against fixed objects, could be a very simple and cost-effective way to arouse a state of PAP prior to sports performance or training sessions which require high force and power outputs. The results of this study imply that the custom made apparatus may be effective in enhancing offensive performance in experienced female softball players by significantly increasing maximal horizontal bat velocity.
Aagaard, P., Simonsen, E. B., Andersen, J. L., Magnusson, P., & Dyhre-Poulsen, P. (2002). Neural adaptation to resistance training: changes in evoked V-wave and H-reflex responses. *Journal of Applied Physiology, 92*(6), 2309-2318.

Baechle T. R., & Earle, R. W. (2008). Essentials of Strength Training and Conditioning. National Strength and Conditioning Association. Champaign, IL: Human Kinetics.

Baker, D. (2003). Acute effect of alternating heavy and light resistances on power output during upper-body complex power training. *Journal of Strength & Conditioning Research, 17*(3), 493–497.

Banister, E. W., Morton, R. H., & Fitz-Clarke, J. (1992). Dose/response effects of exercise modeled from training: physical and biochemical measures. *The Annals of Physiological Anthropology, 11*(3), 345-356.

Bassett, K. E., Szymanski, D. J., Beiser, E. J., Till, M. E., Medlin, G. L., & DeRenne, C. (2011). Effects of various warm-up devices on bat swing velocity of college softball players. *Journal of Strength and Conditioning Research, 25*, S71.

Baudry, S., & Duchateau, J. (2007). Postactivation potentiation in a human muscle: effect on the rate of torque development of tetanic and voluntary isometric contractions. *Journal of Applied Physiology, 102*, 1394-1401.
Behm, D. G., Button, D. C., Barbour, G., Butt, J. C., & Young, W. B. (2004). Conflicting effects of fatigue and potentiation on voluntary force. *Journal of Strength and Conditioning Research, 18*(2), 365-372.

Bevan, H. R., Cunningham, D. J., Tooley, E. P., Owen, N. J., Cook, C. J., & Kilduff, L. P. (2010). Influence of postactivation potentiation on sprinting performance in professional rugby players. *Journal of Strength & Conditioning Research, 24*(3), 701–705.

Brandenburg, J. P. (2005). The acute effects of prior dynamic resistance exercise using different loads on subsequent upperbody explosive performance in resistance-trained men. *Journal of Strength & Conditioning Research, 19*(2), 427–432.

Bridges, C. R., Clark, B. J., Hammond, R. L., & Stephenson, L. W. (1991). Skeletal muscle bioenergetics during frequency-dependent fatigue. *The American Journal of Physiology, 260*(3), C643-C651.

Chatzopoulos, D. E., Michailidis, C. J., Giannakos, A. K., Alexiou, K. C., Patikas, D. A., Antonopoulos, C. B., & Kotzamanidis. C. M. (2007). Postactivation potentiation effects after heavy resistance exercise. *Journal of Strength & Conditioning Research, 21*(4), 1278–1281.

Chiu, L. Z., Fry, A. C., Weiss, L. W., Schilling, B. K., Brown, L. E., & Smith, S. L. (2003). Postactivation potentiation response in athletic and recreationally trained individuals. *Journal of Strength and Conditioning Research, 17*(4), 671-677.
Davis, J. S., Satorius, C. L., & Epstein, N. D. (2002). Kinetic effects of myosin regulatory light chain phosphorylation on skeletal muscle contraction. *Biophysical Journal, 83*, 359-370.

Dawson, B., Goodman, C., Lawrence, S., Preen, D., Polglaze, T., Fitzsimons, M., & Fournier, P. (1997). Muscle phosphocreatine repletion following single and repeated short sprint efforts. *Scandinavian Journal of Medicine and Science in Sports, 7*, 206-213.

DeRenne, C., Ho, K. W., Hetzler, R. K., & Chai, D. X. (1992). Effects of warm up with various weighted implements on baseball bat swing velocity. *Journal of Applied Sport Science Research, 6*(4), 214-218.

Duthie, G. M., Young, W. B., & Aitken, D. A. (2002). The acute effects of heavy loads on jump squat performance: an evaluation of the complex and contrast methods of power development *Journal of Strength & Conditioning Research, 16*(4), 530–538.

Ebben, W. P., Jensen, R. L., & Blackard, D. O. (2000). Electromyographic and kinetic analysis of complex training variables. *Journal of Strength and Conditioning Research, 14*(4), 451-456.

Esformes, J. I., Keenan, M., Moody, J., & Bampouras, T. M. (2011). Effect of different types of conditioning contraction on upper body postactivation potentiation. *Journal of Strength & Conditioning Research, 25*(1), 143-148.
Flyger, N., Button, C., & Rishiraj, N. (2006). The science of softball: implications for performance and injury prevention. *Sports Medicine, 36*(9), 797-816.

Folland, J. P., Wakamatsu, T., & Finland, M. S. (2008). The influence of maximal isometric activity on twitch and H-reflex potentiation, and quadriceps femoris performance. *European Journal of Physiology, 104*, 739-748.

French, D.N., Kraemer, W. J., & Cooke, C. B. (2003). Changes in dynamic exercise performance following a sequence of preconditioning isometric muscle actions. *Journal of Strength and Conditioning Research, 17*(4), 678-685.

Gibbens, M., Kaiser, S., & Youngblood, N. (2010). Who’s on first: a baseball bat performance investigation. *Consortium for Mathematics and Its Applications, 1*-16.

Gilbert, G. & Lees, A. (2005). Changes in the force development characteristics of muscle following repeated maximum force and power exercise. *Ergonomics, 48*(11-14), 1576-1584.

Glaister, M., Stone, M. H., Stewart, A. M., Hughes, M., & Moir, G. L. (2005). The influence of recovery duration on multiple sprint cycling performance. *Journal of Strength & Conditioning Research, 19*(4), 831-837.

Grange, R. W., Cory, C. R., Vandenboom, R., & Houston, M. E. (1995). Myosin phosphorylation augments force-displacement and force-velocity relationships of mouse fast muscle. *American Journal of Physiology, 269*(3 Pt 1), C713-24.
Grange, R. W., Vandenboom, R., & Houston, M. E. (1993). Physiological significance of myosin phosphorylation in skeletal muscle. *Canadian Journal of Applied Physiology, 18*, 229–242.

Gullich, A., & Schmidtbleicher, D. (1996). MVC-induced short-term potentiation of explosive force. *New Studies in Athletics, 4*, 67–81.

Hamada, T., Sale, D. G., MacDougall, J. D., & Tarnopolsky, M. A. (2000). Postactivation potentiation, fiber type, and twitch contraction time in human knee extensor muscles. *Journal of Applied Physiology, 88*(6), 2131-2137.

Hanson, E. D., Leigh, S., & Mynark, R. G. (2007). Acute effects of heavy- and light-load squat exercise on the kinetic measures of vertical jumping. *Journal of Strength & Conditioning Research, 21*(4), 1012–1017.

Harris, R. C., Edwards, R. H., Hultman, E., Nordesjö, L. O., Nylin, B., & Sahlin, K. (1976). The time course of phosphorylcreatine resynthesis during recovery of the quadriceps muscle in man. *Pflugers Archiv, 367*(2), 137-142.

Higuchi, T., Nagami, T., Mizuguchi, N., & Anderson, T. (2013). The acute and chronic effects of isometric contraction conditioning on baseball bat velocity. *The Journal of Strength & Conditioning Research, 27*(1), 216-222.

Hirst, G. D., Redman, S. J., & Wong, K. (1981). Post-tetanic potentiation and facilitation of synaptic potentials evoked in cat spinal motoneurones. *Journal of Physiology, 321*, 97-109.
Hirvonen, J., Nummela, A., Rusko, H., Rehunen, S., & Härkönen, M. (1992). Fatigue and changes of ATP, creatine phosphate, and lactate during the 400-m sprint. *Canadian Journal of Sport Sciences, 17*(2), 141-144.

Hodgson, M., Docherty, D., & Robbins, D. (2005). Post-activation potentiation: Underlying physiology and implications for motor performance. *Sports Medicine, 35*(7), 585-595.

Houston, M. E., Green, H. J., & Stull, J. T. (1985). Myosin light chain phosphorylation and isometric twitch potentiation in intact human muscle. *European Journal of Physiology, 403*(4), 348–352.

Hyrsomallis, C., & Kidgell, D. (2001). Effect of heavy dynamic resistive exercise on acute upper-body power. *Journal of Strength and Conditioning Research, 15*(4), 597-600.

Jensen, R. L., & Ebben, W. P. (2003). Kinetic analysis of complex training rest interval effect on vertical jump performance. *Journal of Strength & Conditioning Research, 17*(2), 345–349.

Kamm, K. E., & Stull, J. T. (2011). Signaling to myosin regulatory light chain in sarcomeres. *Journal of Biological Chemistry, 286*(12), 9941-9947.

Katsumata, H. (2007). A functional modulation for timing a movement: A coordinative structure in baseball hitting. *Human Movement Science, 26*(1), 27-47.
Khamoui, A. V., Brown, L. E., Coburn, J. W., Judelson, D. A., Uribe, B. P., Nguyen, D., Tran, T., Eurich, A. D., & Noffal, G. J. (2009). Effect of potentiating exercise volume on vertical jump parameters in recreationally trained men. *Journal of Strength & Conditioning Research, 23*(5), 1465–1469.

Kilduff, L. P., Bevan, H. R., Kingsley, M. I., Owen, N. J., Bennett, M. A., Bunce, P. J., Hore, A. M., Maw, J. R., Cunningham, D. J. (2007). Postactivation potentiation in professional rugby players: optimal recovery. *Journal of Strength and Conditioning Research, 21*(4), 1134-1138.

Klein, C. S., Ivanova, T. D., Rice, C. L., Garland, S. J. (2001). Motor unit discharge rate following twitch potentiation in human triceps brachii muscle. *Neuroscience Letters, 316*, 153-156.

Liu, C., Liu, Y-C., Kao, Y-C., & Shiang, T-Y. (2011). Effects of training with dynamic moment of inertia bat on swing performance. *Journal of Strength and Conditioning Research, 25*(11), 2999–3005.

Luscher, H. R., Ruenzel, P., & Henneman, E. (1983). Composite EPSPs in motoneurons of different sizes before and during PTP: implications for transmission failure and its relief in Ia projections. *Journal of Neurophysiology, 49*(1), 269-289.

MacDougall, J. D., Ward, G. R., Sale, D. G., & Sutton, J. R. (1977). Biochemical adaptation of human skeletal muscle to heavy resistance training and immobilization. *Journal of Applied Physiology, 43*(4), 700-703.
Magnus, B. C., Takahashi, M., Mercer, J. A., Holcomb, W. R., McWhorter, J. W., & Sanchez, R. (2006). Investigation of vertical jump performance after completing heavy squat exercises. *Journal of Strength and Conditioning Research, 20*(3), 597-600.

Mahfeld, K., Franke, J., & Awiszus, F. (2004). Postcontraction changes of muscle architecture in human quadriceps muscle. *Muscle Nerve, 29*(4), 597-600.

Mayhew, J. L., Johnson, B. D., LaMonte, M. J., Lauber, D., & Kemmler, W. (2008). Accuracy of prediction equations for determining one repetition maximum bench press in women before and after resistance training. *Journal of Strength & Conditioning Research, 22*(5), 1570–1577.

McCann, M. R., & Flanagan, S. P. (2010). The effects of exercise selection and rest interval on postactivation potentiation of vertical jump performance. *Journal of Strength & Conditioning Research, 24*(5), 1285–1291.

Montoya, B. S., Brown, L. E., Coburn, J. W., & Zinder, S. M. (2009). Effect of warm-up with different weighted bats on normal baseball bat velocity. *Journal of Strength and Conditioning Research, 23*(5), 1566–1569.

Moore, R. L, & Stull, J. T. (1984). Myosin light chain phosphorylation in fast and slow skeletal muscles in situ. *The American Journal of Physiology, 247*(5), C462-C471.
Nakamoto, H., Ishii, Y., Ikudome, S., & Ohta, Y. (2012). Kinesthetic aftereffects induced by a weighted tool on movement correction in baseball batting. *Human Movement Science, 31*, 1529-1540.

Neumann, D. A. (2010). *Kinesiology of the Musculoskeletal System: Foundations for Rehabilitation*. St. Louis, MI: Mosby Elsevier.

O’Connor, B., Simmons, J., and O’Shea, P. (1989). *Weight Training Today*. St. Paul, MN: West Publishing.

Otsuji, T., Abe, M., & Kinoshita, H. (2002). After-effects of using a weighted bat on subsequent swing velocity and batters’ perceptions of swing velocity and heaviness. *Perceptual and Motor Skills, 94*, 119-126.

Palmer, B. M., & Moore, R. L. (1989). Myosin light chain phosphorylation and tension potentiation in mouse skeletal muscle. *The American Journal of Physiology, 257*(5), C1012- C1019.

Palmieri, R. M., Ingersoll, C. D., & Hoffman, M. A. (2004). The Hoffmann reflex: methodologic considerations and applications for use in sports medicine and athletic training research. *Journal of Athletic Training, 39*(3), 268-277.

Pillmeiera, C., Litzenbergera, S., & Saboa, A. (2012). The effect of on-deck warm-up routines in baseball on bat velocity, muscular activity and intensity in time-frequency space. *Procedia Engineering, 34*, 230–235.
Rassier, D. E., & Macintosh, B. R. (2000). Coexistence of potentiation and fatigue in skeletal muscle. *Brazilian Journal of Medical and Biological Research, 33*(5), 499–508.

Reyes, G. F., & Dolny, D. G. (2009). Acute effects of various weighted bat warm-up protocols on bat velocity. *Journal of Strength and Conditioning Research, 23*(7), 2114-2118.

Reyes, G. F., Dickin, D. C., Dolny, D. G., & Crusat, J. K. (2010). Effects of muscular strength, exercise order, and acute whole-body vibration exposure on bat swing speed. *Journal of Strength and Conditioning Research, 24*(12), 3234-3240.

Reynolds, J. M., Gordon, T. J., & Robergs, R. A. (2006). Prediction of 1 repetition maximum strength from multiple repetition maximum testing and anthropometry. *Journal of Strength & Conditioning Research, 20*(3), 584–592.

Rixon, K. P., Lamont, H. S., & Bemben, M. G. (2007). Influence of type of muscle contraction, gender, and lifting experience on postactivation potentiation performance. *Journal of Strength and Conditioning Research, 21*(2), 500-505.

Robertson, G. E., Caldwell, G. E., Hamill, J., Kamen, G. & Whittlesey, S. N. (2004). Research Methods in Biomechanics, Champaign, IL: Human Kinetics.

Ryder, J. W., Lau, K. S., Kamm, K. E., & Stull, J. T. (2007). Enhanced skeletal muscle contraction with myosin light chain phosphorylation by a calmodulin-sensing kinase. *The Journal of Biological Chemistry, 282*(28), 20447-20454.
Scott, S., & Gray, R. (2010). Switching tools: perceptual-motor recalibration to weight changes. *Experimental Brain Research, 201*, 177-189.

Shaffer, B., Jobe, F. W., Pink, M., & Perry, J. (1993). Baseball batting: an electromyographic study. *Clinical Orthopaedics and Related Research, 292*, 285-293.

Smith, J. C., & Fry, A. C. (2007). Effects of a ten-second maximum voluntary contraction on regulatory myosin light-chain phosphorylation and dynamic performance measures. *Journal of Strength and Conditioning Research, 21(1)*, 73-76.

Southard, D. & Groomer, L. (2003). Warm-up with baseball bats of varying moments of inertia: Effect on bat velocity and swing pattern. *Research Quarterly for Exercise and Sport, 74(3)*, 270-276.

Stuart, D. S., Lingley, M. D., Grange, R. W., & Houston, M. E. (1988). Myosin light chain phosphorylation and contractile performance of human skeletal muscle. *Canadian Journal of Physiology and Pharmacology, 66(1)*, 49-54.

Stull, J. T., Kamm, K. E., & Vandenboom, R. (2011). Myosin light chain kinase and the role of myosin light chain phosphorylation in skeletal muscle. *Archives of Biochemistry and Biophysics, 10(2)*, 120-128.

Sweeney, H. L., Bowman, B. F., & Stull, J. T. (1993). Myosin light chain phosphorylation in vertebrate striated muscle: regulation and function. *The American Journal of Physiology, 264*, C1085-C1095.
Szczesna, D., Zhao, J., Jones, M., Zhi, G., Stull, J., & Potter, J. (2001). Phosphorylation of the regulatory light chains of myosin affects Ca2+ sensitivity of skeletal muscle contraction. *Journal of Applied Physiology, 92*(4), 1661-1670.

Szymanski, D. J., Bassett, K. E., Beiser, E. J., Till, M. E., Medlin, G. L., Beam, J. R., & DeRenne, C. (2012). Effect of various warm-up devices on bat velocity of intercollegiate softball players. *Journal of Strength & Conditioning Research, 26*(1), 199–205.

Szymanski, D. J., Beiser, E. J., Bassett, K. E., Till, M. E., Medlin, G. L., Beam, J. R., & DeRenne, C. (2011). Effect of various warm-up devices on bat velocity of intercollegiate baseball players. *Journal of Strength & Conditioning Research, 25*(2), 287–292.

Szymanski, D. J., DeRenne, C., & Spaniol, F. J. (2009). Contributing factors for increased bat swing velocity. *Journal of Strength & Conditioning Research, 23*(4), 1338–1352.

Szymanski, D. J., McIntyre, J. S., Szymanski, J. M., Bradford, J. T., Schade, R. L., Madsen, N. H., & Pascoe, D. D. (2007a). Effect of torso rotational strength on angular hip, angular shoulder, and linear bat velocities of high school baseball players. *Journal of Strength & Conditioning Research, 21*(4), 1117-1125.

Szymanski, D. J., Szymanski, J. M., Bradford, J. T., Schade, R. L., Madsen, N. H., & Pascoe, D. D. (2007b). Effect of twelve weeks of medicine ball training on
high school baseball players. *Journal of Strength & Conditioning Research, 21*(3), 894-901.

Szymanski, D. J., Szymanski, J. M., Schade, R. L., Bradford, J. T., McIntyre, J. S., DeRenne, C., & Madsen, N. H. (2010). The relation between anthropometric and physiological variables and bat velocity of high-school baseball players before and after twelve weeks of training. *Journal of Strength & Conditioning Research, 24*(11), 2933-2943.

Tesch, P. A., Thorsson, A., & Fujitsuka, N. (1989). Creatine phosphate in fiber types of skeletal muscle before and after exhaustive exercise. *Journal of Applied Physiology, 66*(4), 1756-1759.

Tillin, N. A., & Bishop, D. (2009). Factors modulating post-activation potentiation and its effect on performance of subsequent explosive activities. *Sports Medicine, 39*(2), 147-166.

Trimble, M. H., & Harp, S. S. (1998). Postexercise potentiation of the H-reflex in humans. *Medicine and Science in Sports and Exercise, 30*(6), 933–941.

Vandenboom, R., & Houston, M. E. (1996). Phosphorylation of myosin and twitch potentiation in fatigued skeletal muscle. *Canadian Journal of Physiology and Pharmacology, 74*(12), 1315-1321.

Vandenboom, R., Grange, R. W., & Houston, M. E. (1995). Myosin phosphorylation enhances rate of force development in fast-twitch skeletal muscle. *The American Journal of Physiology, 268*(3), C596-C603.
Veroni, K., & Brazier, R. (2006). Coaching Fastpitch Softball Successfully. Champaign, IL: Human Kinetics.

Weber, K. R., Brown, L. E., Coburn, J. W., & Zinder, S. M. (2008). Acute effects of heavy-load squats on consecutive squat jump performance. Journal of Strength & Conditioning Research, 22(3), 726-730.

Welch, C. M., Banks, S. A., Cook, F. F., & Draovitch, P. (1995). Hitting a baseball: a biomechanical description. Journal of Orthopedic Sports Physical Therapy, 22(5), 193-201.

Wilson, J. M., Miller, A. L., Szymanski, D. J., Duncan, N. M., Andersen, J. C., Alcantara, Z. G., Morrison, T. J., & Bergman, C. J. (2012). Effects of various warm-up devices and rest period lengths on batting velocity and acceleration of intercollegiate baseball players. Journal of Strength & Conditioning Research, 26(9), 2317-2323.

Wilson, L. R., Gandevia, S. C., & Burke, D. (1995). Increased resting discharge of human spindle afferents following voluntary contractions. Journal of Physiology, 488(3), 833-840.

Young, W.B., Jenner, A., & Griffiths, K. (1998). Acute enhancement of power performance from heavy load squats. Journal of Strength & Conditioning Research, 12(2), 82-84.

Zhi, G., Ryder, J. W., Huang, J., Ding, P., Chen, Y., Zhao, Y., Kamm, K. E., & Stull, J. T. (2005) Myosin light chain kinase and myosin phosphorylation effect
frequency-dependent potentiation of skeletal muscle contraction.

*Proceedings of the National Academy Sciences of the United States of America, 102*(48), 17519-17524.
Appendix A

HUMAN SUBJECTS REVIEW FORM AND RESPONSES

1. What is your research question, or the specific hypothesis?

The experimental hypothesis states that the potentiating warm-up utilizing isometric contractions will elicit a significant increase in bat velocity when compared to subjects’ established baseline bat velocity.

2. What are the potential benefits of the proposed research to the field?

Bat velocity has been deemed crucial for success in hitting. There is very little time for the perceptual-decision making process, using information about the flight of the pitch to organize the swing motion (Katsumata, 2007). Because of the time needed to judge a pitch, it is favorable for the hitter to wait until the last possible moment before initiating their motion towards the ball, rather than attempt to react to the pitch mid-swing (Katsumata, 2007). A decreased swing time, or higher bat velocity, provides the hitter more time to observe the oncoming pitch, allowing for a more accurate evaluation of the speed, location, and movement of the pitch, increasing the hitter’s chances of making solid contact with the ball (Reyes, Dickin, Dolny, & Crusat, 2010). In this regard, bat velocity is even more important to offensive success in softball players, when compared to baseball players. In softball, pitches not only travel in a high to low trajectory, as they do in baseball, but they also travel in a low to high trajectory with underhand rise-balls. In addition, the relationship between bat velocity and the distance the ball travels after impact has been well-established (Reyes, Dickin, Dolny, & Crusat, 2010). Greater bat velocity facilitates an increase in batted ball velocity and distance, increasing the chances of successful at bats (Szymanski, McIntyre, Szymanski, Bradford, Schade, Madsen, & Pascoe, 2007a).

The decreased response time in softball hitting combined with the reported lower bat velocities in softball hitters, when compared to baseball hitters (Flyger, Button, & Rishiraj, 2006), shows the need for a warm-up device that can increase bat velocity in softball players. Such a device could improve the athlete’s offensive performance and give coaches another medium with which they could prepare their athletes for competition.

Furthermore, softball provides a unique setting in which to utilize the PAP phenomenon. Unlike most other team sports, the timing of individual offensive performance is fairly predictable due to having an established batting order. The development of a successful pre-batting warm-up protocol would have important implications in the sport.
3. What are the potential benefits, if any, of the proposed research to the subjects?

Upon completion of the study, the subjects will know their maximal bat swing velocity, as well as their predicted one repetition bench press and back squat maximum value, which can be used in the future to develop well designed resistance training programs. Subjects will also get a report stating whether or not they exhibited post-activation potentiation after the designed warm-up protocol. This information may be used in training or competition to possibly increase bat velocity.

4. Answer a), then answer either b) or c) as appropriate.

a. Describe how you will identify the subject population, and how you will contact key individuals who will allow you access to that subject population or database.

The population sample will consist of female softball players between the ages of sixteen and twenty-five, who have at least five years of experience playing competitive fastpitch softball. All subjects under the age of eighteen are required to have parent or guardian permission prior to any involvement with this study. Both right and left handed hitters will be recruited for analysis. A form requesting permission to contact the athletes will be given to and signed by the head softball coach of each softball team before the researcher contacts the athletes. It is understood that all subjects participate in softball year-around. Athletes will be instructed to continue their normal training (including resistance training, conditioning, and sports specific practice), except during the day of testing.

b. Describe how you will recruit a sample from your subject population, including possible use of compensation, and the number of subjects to be recruited.

At least thirty subjects will be recruited to participate in this study. The softball players will be recruited from both the Western Washington University softball team and select softball teams in western Washington. Inclusion for this study demands that subjects be free of any musculoskeletal or neurological impairment or injury. Athletes who participate in this study will not be compensated for their participation.

OR

c. Describe how you will access preexisting data about the subjects.

N/A
5. Briefly describe the research methodology. Attach copies of all test instruments/questionnaires that will be used.

**Instrumentation:** The isometric potentiating protocol utilized a device designed by the author and engineered by Scientific Technical Services at Western Washington University. Horizontal bat velocity will be measured during each swing trial using a high speed video camera, filming at four-hundred-and-twenty frames per second. The camera will be positioned perpendicular to the hitting zone, in the sagittal plane. A meter stick will be aligned in the field of view of the video camera, serving as a distance reference, which will be used to calculate bat displacement per video frame. Bright reflective tape will be connected to the barrel of a Louisville Slugger Catalyst fastpitch bat (Louisville Slugger, Louisville, KY) of standard length, 83.8 centimeters (thirty-three inches), and weight, twenty-three ounces. This tape will serve as a marker during filming in order to make the manual digitization consistent throughout the trials. Additionally, a spot light will be positioned on the subject and an all-black backdrop was created to aid the digitization process. During the trials, subjects will swing at a teed twelve inch, game-ball yellow, Lite-Flite® softball (Jugs Sports, Tualatin, OR). Measuring the distance that the reflective marker travels in each frame of the video will determine bat velocity in meters per second. The video data will be analyzed using MaxTRAQ motion analysis software (Innovision Systems, Inc., Columbiaville, MI).

**Measurement techniques and testing procedures.** Data collection will take place at Western Washington University in the Parberry Strength Center and the Biomechanics Laboratory. Two separate sessions will be implemented, the first to administer the potentiating warm-up protocol and measure bat velocity, and the second to conduct strength testing.

During the first session, subjects will complete a standardized warm-up consisting of general, dynamic, and specific phases. After a four minute rest period, the subjects will complete one set of five practice swings, increasing in intensity, with the testing bat. The practice swings will be followed by one set of five warm-up swings hitting a teed ball. The last three swings will be performed at maximal effort. During a two minute recovery period, the high speed camera will be set in position with a tripod. After the two minutes, the subjects will be told to assume a stance and swing as if they were in a game situation. Rest periods of twenty-seconds will be given between swings to recover, and simulated the time taken between pitches in a game situation. Three maximal swings will be recorded. The average horizontal bat velocity produced will represent the subject’s baseline bat velocity.
Once baseline bat velocity is established, subjects will be given ten minutes to recover. During this time, clear and like instructions regarding the phase specific isometric conditioning contraction will be given to each subject (see script in Appendix C). Subjects will be instructed to maximally contract muscles, pulling the handle of the device, while no visible change in joint angle occurs. Three maximal effort isometric contractions will be sustained in this position for five seconds. Each maximal effort will be separated by thirty seconds of recovery.

Upon completion of the potentiating protocol, each subject will return to the batter’s box and will be instructed to swing the bat maximally at the teed softballs, just as they have done previously. Trials will be taken at one minute, two minutes, four minutes, six minutes, eight minutes, ten minutes, and twelve minutes post-exercise. All trials will be recorded with the high speed video camera. Each trial will be saved with a subject number and trial number. All trials will be imported into MaxTRAQ motion analysis software (Innovision Systems, Inc., Columbiaville, MI) and will be manually digitized by the researcher.

During the second session, subjects will complete a standardized warm-up consisting of general, dynamic, and specific phases. Injury prevention is a primary concern of the researcher, the coaches, and the athletes involved in this study. Therefore, predicted one repetition maximum (1-RM) using multiple repetition (repetitions to fatigue) testing has been selected for this study, instead of true maximal testing. Given the reliability and accuracy of the equation created by O’Connor and colleagues (1989), this equation (1-RM = (0.025 x [rep wt. x RTF]) + rep wt.) was chosen to predict 1-RM strength for the bench press and back squat for the current study. Though all subjects will have had previous weight training experience, prior to testing, proper technique for the bench press and back squat will be explained to the athletes according to the standards of the National Strength and Conditioning Association.

Following the warm-up, the athletes will complete ten repetitions at 50% of their self-estimated 1-RM. After a four minute rest period, a second set will be completed and consist of five repetitions at 75% of the subjects’ self-estimated 1-RM. Following another four minute rest period, the weight will be increased by 10-15% and each subject will be asked to lift the weight for as many repetitions as possible until failure. Failure is defined as the inability of the subject to attain proper depth during the eccentric (down) phase and full extension during the concentric (up) phase of the exercises. Three spotters will be present during every repetition. Appropriate form and depth of both exercises will be evaluated by a certified strength and conditioning specialist. Each subject’s load and number of repetitions to failure will
be recorded and put into the prediction equation to estimate 1-RM strength for each exercise. Subjects will be given verbal encouragement during all testing sessions.

See attached “research protocol checklist and data logging” sheet.

6. **Give specific examples (with literature citations) for the use of your test instruments/questionnaires, or similar ones, in previous similar studies in your field.**

Bat velocity has been measured using a variety of different methods in the literature. Reyes, et al. (2010) used high speed video cameras (filming two-hundred frames per second) to record each swing and analyzed the data using Streampix, 4.13.3 video program (Norpix, Montreal, Quebec, Canada). Similarly, Welch and colleagues (1995), Szymanski, et al., (2007a), and Szymanski, et al., (2010) used motion analysis software to collect swing data with reflective markers and six cameras which, too, captured the swing at two-hundred frames per second. The PEHR department at Western Washington University uses MaxTRAQ motion analysis software (Innovision Systems, Inc., Columbiaville, MI) in the Biomechanics (Kinesiology 311) course to analyze high speed videos. Since the MaxTRAQ motion analysis software is readily available and very accurate, it was chosen for the current study.

7. **Describe how your study design is appropriate to examine your question or specific hypothesis. Include a description of controls used, if any.**

This study is a single group repeated measures design to analyze the effect of a potentiating warm-up on maximal horizontal bat velocity. Thirty volunteers will participate in the study. Post-isometric warm-up bat velocity results will be compared to each subjects’ baseline bat velocity, as subjects will serve as their own controls. This study will also employ t-tests to compare means of the baseline measures of absolute strength and relative strength between potentiated and non-potentiated groups.

This study design is appropriate to examine the specific hypothesis, investigating the effect of a high-intensity isometric warm-up on maximal horizontal bat velocity. This study will examine the change in bat velocity, comparing the subjects’ established baseline bat velocity, to their bat velocity after the warm-up.

8. **Give specific examples (with literature citations) for the use of your study design, or similar ones, in previous similar studies in your field.**

Multiple studies have employed a similar protocol using a repeated measures design when investigating the post-activation potentiation phenomenon (Kilduff, et al.,
2007; Weber, Brown, Coburn, & Zinder, 2008; Young, Jenner, & Griffiths, 1998). As the measurement of PAP requires a comparison of an individual’s baseline value, usually either power or rate of force development, to a post-potentiating warm-up value, a repeated measures design is essential.

9. Describe the potential risks to the human subjects involved.

As with any exercise or resistance training, there are risks of muscle, tendon, ligament, and spinal injury that will be present. Some discomfort when performing the strength testing and the isometric potentiating warm-up is expected, as it is asked that the subjects give a maximal effort during both sessions.

10. If the research involves potential risks, describe the safeguards that will be used to minimize such risks.

In order to ensure the safety of all subjects, each exercise will be explained in detail and monitored intently for proper form and safe mechanics. Multiple spotters will be present during exercise testing sessions. To minimize the risk of fatigue, rest period are given after every short bout of physical exertion.

11. Describe how you will address privacy and/or confidentiality.

Any and all data collected will be kept completely confidential and will be stored and analyzed by subject number only. Only the primary researcher will have access to the records.

12. If your research involves the use of schools (pre-kindergarten to university level) or other organizations (e.g., community clubs, companies), please attach a clearance letter from an administrator from your research site indicating that you have been given permission to conduct this research. For pre-kindergarten to grade 12 level schools, an administrator (e.g. principal or higher) should issue the permission. For post-secondary level schools the class instructor may grant permission. For Western Washington University, this requirement of a clearance letter is waived if you are recruiting subjects from a scheduled class. If you are recruiting subjects from a campus group (not a class) at Western Washington University, you are required to obtain a clearance letter from a leader or coordinator of the group.

13. If your research involves the use of schools (pre-kindergarten to university level) or other organizations (e.g., community clubs, companies), and you plan to take still or video pictures as part of your research, please complete
a) to d) below:

a. Who have you contacted at the school district or organization involved, to determine the policy on the use of photography in the school or organization?

The executive directors of the select softball organizations that will be used in this study have all been contacted. None of the organizations have policies against the use of photography or videotaping. No documentation for photography/videotaping policies were available.

b. Explain how your research plan conforms to the policy on the use of photography in the school or organization.

All subjects will sign the attached "permission to videotape" form prior to participation in the study.

c. Attach a copy of the school district or organization policy on the use of photography at the schools or organization.

Not applicable.

d. Explain how you will ensure that the only people recorded in your pictures will be the ones that have signed a consent form.

A signed “permission to videotape” form will be obtained before every testing session. Without permission to videotape, the subjects will not be able to participate in the study.

In addition, please attach the following information:

1. A bibliography relevant to the subject matter of the proposed research.

See attached

2. A copy of the informed consent form (a checklist is attached for you to use as a guide).

See attached

3. A current curriculum vitae.

See attached
4. A copy of the Certificate of Completion for Human Subjects Training from the online human subjects training module, for each person involved in the research who will have any contact with the subjects or their data.

See attached

5. If your subjects are required to turn in a physician clearance form prior to participation, include a copy of the blank form.

N/A


Appendix B

PERMISSION FORM TO CONTACT THE ATHLETES FOR TESTING

Letter of permission:
As the head coach of the Western Washington University women's softball team, I, 
____________________________, approve Sheryl Gilmore’s thesis research on the WWU varsity 
softball team, which includes submaximal strength testing, bat velocity testing using 
multiple swing trials (via hitting a ball off a tee), and the use of an isometric potentiating 
warm-up protocol.

____________________________________
Coach’s Name (Printed)                   ___/___/_______

____________________________________
Coach’s Signature

Date
PERMISSION FORM TO CONTACT THE ATHLETES FOR TESTING

Letter of permission:
As the coach of the Washington Warriors Fastpitch Club, I, ____________________________, approve Sheryl Gilmore’s thesis research on the Washington Warriors softball team, which includes submaximal strength testing, bat velocity testing using multiple swing trials (via hitting a ball off a tee), and the use of an isometric potentiating warm-up protocol.

____________________________________
Coach’s Name (Printed)  ___/___/______

____________________________________
Coach’s Signature
INFORMED CONSENT FOR EXERCISE TESTING

You are invited to participate in a research study conducted by Sheryl Gilmore, from the department of Physical Education, Health, and Recreation at the Western Washington University. This study involves research on post-activation potentiation. Post-activation potentiation is the phenomenon of enhanced power performance following a specific pre-load activity, typically performed at maximal, or near maximal, intensity. The softball swing is an explosive power activity and may be enhanced by this phenomenon. The purpose of this research is to investigate the acute effect of a high-intensity isometric potentiating warm-up on subsequent maximal bat velocity in experienced female softball players. Research indicates that post-activation potentiation is primarily exhibited in well trained individuals, and that absolute strength is correlated to the percent performance enhancement. Therefore, strength testing will be analyzed in conjunction with bat velocity. As optimal recovery duration following the potentiating warm-up can be highly variable, swing trials will be conducted at pre-determined intervals in order to identify the recovery time which may allow for maximal benefits.

Given your participation, you will meet for two testing sessions at Western Washington University, one in the biomechanics lab and the other in Parberry strength center. The sessions will include the following expectations:

Session one (bat velocity testing): A standardized warm-up will be completed, followed by a four minute rest period. Then, one set of five practice swings with the testing bat will be performed. The practice swings will be followed by one set of five warm-up swings hitting a teed ball. The last three swings will be performed at maximal effort. After a short recovery, baseline bat velocity will be tested. You will, again, swing maximally, hitting a ball off of a batting tee. Short rest periods will be given between swings. Three maximal swings will be recorded using a high speed video camera. The average horizontal bat velocity produced will represent baseline bat velocity. After a ten minute recovery, maximal muscle contractions will be performed by pulling against the handle of a device (simulating a bat handle), while in the early phase of your swing. During this contraction, no movement or visible change in joint angle will occur. Three maximal effort isometric contractions will be sustained in this position for five seconds, at which time manual muscle testing may be performed by the researcher. Each maximal effort will be separated by thirty seconds of recovery. You will then return to the batter’s box and swing the bat maximally at the teed softballs. Swing trials will be taken at one, two, four, six, eight, ten, and twelve minutes post- potentiation preparation. All trials will be recorded with the high speed video camera.

Session two (submaximal strength testing): A standardized warm-up will be completed, followed by a four minute rest period. Researchers will then review proper technique for the bench press and back squat according to the standards of the National Strength and Conditioning Association. Ten repetitions of the back squat or bench press will be performed at 50% of your self-estimated one repetition maximum (1-RM). After a four minute rest period, a second set will be completed,
consisting of five repetitions at 75% of self-estimated 1-RM. Following another rest period, the weight will be increased by 10-15% and will be lifted for as many repetitions as possible, until fatigue. For your safety, three spotters will be present during every repetition. The load and number of repetitions to fatigue will be recorded and put into a prediction equation to estimate 1-RM strength for each exercise.

As with any exercise or resistance training, there are risks of muscle, tendon, ligament, and spinal injury that are present. Some discomfort when performing the strength testing and the isometric potentiating warm-up is expected, as it is asked that you give a maximal effort during both sessions. You may withdraw from participation in this study at any time, without penalty.

The benefits of this research are that you will know your maximal bat swing velocity, as well as your predicted one repetition bench press and back squat maximum value, which can be used in the future to develop well designed resistance training programs. You will also get a report stating whether or not you exhibited post-activation potentiation after the designed warm-up protocol. This information may be used in training or competition to possibly increase your bat velocity. The results of this study may aid in future research.

Any questions you may have regarding the study procedures will be answered by the primary researcher (Sheryl Gilmore) who can be contacted at gilmors2@students.wwu.edu or 425-773-7474. Any questions about your rights as a research subject should be directed to: the WWU Human Protections Administrator (HPA), 360-650-3220. If any injury or adverse effect of this research is experienced you should contact Sheryl Gilmore, or the HPA.

Any and all data collected will be kept completely confidential and will be stored and analyzed by subject number only. Only the primary researcher will have access to your records.

Your signature indicates that you have read and understand the information provided above, that you willingly agree to participate, that you may withdraw your consent at any time and discontinue participation without penalty, that you have received a copy of this form, and that you are not waiving any legal claims, rights or remedies.

_______________________________________________  ____/____/_______
Participant Name (Printed)                      Date

_______________________________________________
Participant Signature
If you are under 18 years of age, you will need the consent of your parent or guardian to participate in this study.

For parent or guardian:

I have read the above description and understand the expectations for my child’s participation.

I ___agree (___ do not agree) to permit my child to participate in this study

____________________________________  ___/___/_______
Parent or Guardian Name (Printed)  Date

____________________________________
Parent or Guardian Signature
Appendix D

PERMISSION TO VIDEOTAPE

Permission to video record the swing trials are required for participation in this study, as bat velocity will be measured using video analysis software. I, ____________________________, hereby give the investigator, Sheryl Gilmore, permission to photograph and / or videotape my participation in this study. Furthermore, I give the investigator, Sheryl Gilmore, permission to use photographs or videotape recordings of me when presenting this research in educational and professional venues, only as long as I am not personally identifiable.

_______________________________________________
Participant Name (Printed)

__/___/__________
Date

_______________________________________________
Participant Signature

If you are under 18 years of age, you will need the consent of your parent or guardian.

I ___ permit (___ do not permit) my child to be photographed and / or videotaped during this study.

_______________________________________________
Parent or Guardian Name (Printed)

__/___/__________
Date

_______________________________________________
Parent or Guardian Signature
### Appendix E

**RESEARCH PROTOCOL CHECKLIST AND DATA LOGGING**

| Date | Time (Begun, Completed) |
|------|-------------------------|
| Subject Number | Age (yrs) |
| Height (in) | Weight (lbs) |

**Injury History**

| Bats | Right / Left | Years of Experience |
|------|--------------|---------------------|
| Consent Form? | Yes / No | Videotaping Form? | Yes / No |
| Explanation of test? | Yes / No | Subject on Master Sheet? | Yes / No |
| Questions? | Yes / No | Video sheets prepared? | Yes / No |

**Room set-up?**

- Proper clothing for reading?
- High Speed Camera? Charged? Set at 420 fps?
- Meter stick in place?
- Tee set to proper height? (height of umbilicus during the blocking phase of their swing)
- Balls in bucket?
- Bat ready? Markers on?
- Assistants aware of role?
- PAP device in place?

**Warm-up completed?**

- Jog on a treadmill for 2 minutes at 6 miles per hour
- 30 seconds tip-toe walking arm-circles
- 30 seconds cross-body shoulder slaps
- Lunge to torso twist (5 repetitions on each leg)
- Walking knee hugs (5 repetitions on each leg)
- Walking quad stretches (5 repetitions on each leg)
- Inverted hamstring stretch (5 repetitions on each leg)
- Monster walks (10 yards)
- Side-shuffles (10 yards)
- High knees (10 yards)
- 4 minute rest period
- 1 set of 5 dry swings (with testing bat), increasing in intensity.
- 1 set of 5 warm-up swings hitting a teed ball (the last three swings performed at maximal effort).

2 minute rest

**2 minute rest & final testing set-up**

- Tripod in place?
- Cameraman with sheets?
- Ball placer?
- Timer?
### Baseline BV Testing

- Tell subject:
  - “Assume a stance and swing as if you were in a game situation”

- To account for bat angle and location of bat-ball impact, tell subject to:
  - “Drive every ball on a line, up the middle, towards what would be center field” – Point to target

- 20 second rest periods between swings to recover between swings to simulate the time taken between pitches in a game situation.

- 3 trials recorded?

- The three swings will be averaged for analysis and considered to be the subject’s baseline bat velocity.

### 10 minute recovery & PAP set-up

- 10 min recovery for subject

- During this time, give instructions regarding the phase specific isometric conditioning contraction to subject

- Adjust PAP strap to shoulder level of subject and instruct them on use

- Tell subject:
  - “Grip the handle as you would your bat and get into your stance. Slowly progress through your swing motion, initiated in the legs, and stop in the early swing phase, approaching “slot” position (elbow and knee of the trailing arm and leg are aligned vertically and the hips are neither fully closed nor fully open). While in this position, the chain should be stretched tight, and any further movement forward in the swing will be prohibited by the strap.” (DEMONSTRATE and set-up subject)

  - “Once you are in this position, you are ready to begin the warm-up. On the command ‘GO’ you will maximally contract the muscles involved in the swing, as if attempting to break free and finish your swing. To ensure that you are properly activating the muscles involved in this position, I will randomly perform quick manual muscle tests on the trail leg biceps femoris and gluteus maximus, the abdominal obliques, and the lead arm posterior deltoid and triceps during each maximal voluntary contraction.”

  - “You will perform 3 maximal effort isometric contractions, sustained in this position for 5 seconds. Release the contraction on the command ‘RELEASE’. Each contraction will be separated by 30 seconds of recovery. During these 30 seconds you will stay in the same spot, relaxed, holding the handle of the device.”

  - “As a reminder, you can stop the test at any time. Do you have any questions?”
“After this warm-up, you will immediately move back over to the tree and take seven swing trials at various intervals over twelve minutes. Are you ready?”

- Commence warm-up
  - 5 seconds on – “GO”, cue subject, MMT, “RELEASE”
  - 30 seconds off – 5 second countdown
  - 5 seconds on – “GO”, cue subject, MMT, “RELEASE”
  - 30 seconds off – 5 second countdown
  - 5 seconds on – “GO”, cue subject, MMT, “RELEASE”
  - “DROP STRAP - MOVE TO BATTING TEE”
  - CONTINUE TIMING – Swing trials starts after 1 minute

### Post-PAP Bat Velocity Testing

- Assistants ready?
  - Ball on tee
  - Camera Ready
  - Camera Sheets Ready
  - “You will swing at intervals over the next 12 minutes – Please swing maximally on the command “SWING”. Please remember to try and hit the ball on a line, up the middle.”
  - Observe swing trials
  - Timer command “SWING” at 1 minute
    - Record - Change sheet – Ball on
  - Timer command “SWING” at 2 minutes
    - Record - Change sheet – Ball on
  - Timer command “SWING” at 4 minutes
    - Record - Change sheet – Ball on
  - Timer command “SWING” at 6 minutes
    - Record - Change sheet – Ball on
  - Timer command “SWING” at 8 minutes
    - Record - Change sheet – Ball on
  - Timer command “SWING” at 10 minutes
    - Record - Change sheet – Ball on
  - Timer command “SWING” at 12 minutes
    - Record

### Conclude Testing Session #1

- Get their e-mail address to send them results, thank them, allow them to leave
- Save each recorded swing with a subject number and trial number.
- Import all trials into MaxTRAQ motion analysis software (Innovision Systems, Inc., Columbiaville, MI)
- Manually digitize and save excel file “Subject#_(Pre or Post)_Trial#”
### Session 2 – Strength Testing

| Date | Time (Begun, Completed) |
|------|-------------------------|
|      |                         |

| Subject Number | Age (yrs) | Height (in) | Weight (lbs) |
|----------------|-----------|-------------|--------------|
|                |           |             |              |

| Injury History |
|----------------|
|                |

#### Warm-up completed?

| Yes / No |
|----------|
|          |

- □ Jog on a treadmill for 2 minutes at 6 miles per hour
- □ Walking knee hugs (5 repetitions on each leg)
- □ Lunge to torso twist (5 repetitions on each leg)
- □ Walking quad stretches (5 repetitions on each leg)
- □ Inverted hamstring stretch (5 repetitions on each leg)
- □ Wall slides (5 repetitions)
- □ Cross-body shoulder slaps (5 repetitions)
- □ Push-ups (5 repetitions)
- □ 4 minute rest period

#### Bench Press Technique Explained?

| Yes / No | Back Squat Technique Explained? |
|----------|---------------------------------|
|          |                                 |

- □ Predicted 1-RM Bench Press (lbs)
- □ Predicted 1-RM Back Squat (lbs)
- □ 50%
- □ 75%
- □ 90%
| LOAD _________ lbs | LOAD _________ lbs |
|---------------------|---------------------|
| REPS TO FAILURE ________ | REPS TO FAILURE ________ |

Enter data into equation: 

\[1-RM = (0.025 \times [\text{rep wt.} \times \text{RTF}]) + \text{rep wt.}\]

Predicted 1-RM bench press: ________ lbs 

Predicted 1-RM back squat: ________ lbs
Table 3.
Raw Data for Subject Characteristics.

| Subject # | Age (yrs) | Exp. (yrs) | Ht. (cm) | Wt. (kg) | Est. 1RM Bench (kg) | Est. 1RM Squat (kg) |
|-----------|-----------|------------|----------|----------|--------------------|--------------------|
| 1         | 21        | 11         | 173      | 86.3     | 52.73              | 100.00             |
| 2         | 18        | 10         | 168      | 71.7     | 48.64              | 64.09              |
| 3         | 23        | 11         | 170      | 68.9     | 48.18              | 74.09              |
| 4         | 18        | 10         | 163      | 67.6     | 48.64              | 75.91              |
| 5         | 22        | 15         | 65       | 66.8     | 40.45              | 80.91              |
| 6         | 21        | 14         | 163      | 56.8     | 38.18              | 79.09              |
| 7         | 19        | 13         | 165      | 70.5     | 40.45              | 79.09              |
| 8         | 20        | 14         | 165      | 61.4     | 38.18              | 64.09              |
| 9         | 20        | 14         | 160      | 61.4     | 34.09              | 70.45              |
| 10        | 19        | 14         | 188      | 100.1    | 49.55              | 64.55              |
| 11        | 25        | 20         | 179      | 86.3     | 49.55              | 80.91              |
| 12        | 23        | 15         | 160      | 61.4     | 48.64              | 89.55              |
| 13        | 18        | 13         | 62       | 54.5     | 33.18              | 58.64              |
| 14        | 22        | 12         | 176      | 66.9     | 31.82              | 67.73              |
| 15        | 20        | 10         | 168      | 68.9     | 34.09              | 70.45              |
| 16        | 21        | 6          | 178      | 70.1     | 40.45              | 74.09              |
| 17        | 25        | 13         | 186      | 95.5     | 52.73              | 90.45              |
| 18        | 25        | 17         | 163      | 70.5     | 53.64              | 107.73             |
| 19        | 17        | 11         | 165      | 72.7     | 40.45              | 70.45              |
| 20        | 16        | 8          | 165      | 59.9     | 38.18              | 64.09              |
| 21        | 18        | 9          | 169      | 63.5     | 48.64              | 74.09              |
| 22        | 18        | 7          | 170      | 57.6     | 38.18              | 70.45              |
| 23        | 17        | 8          | 178      | 68.5     | 48.64              | 75.91              |
| 24        | 18        | 7          | 160      | 55.3     | 31.82              | 60.00              |
| 25        | 16        | 10         | 175      | 70.5     | 48.64              | 74.09              |
| 26        | 18        | 10         | 180      | 65.9     | 40.45              | 64.09              |
| 27        | 18        | 9          | 163      | 58.8     | 48.64              | 70.45              |
| 28        | 20        | 11         | 170      | 78.9     | 49.55              | 89.55              |

| Subject Information | Strength Testing |
|---------------------|-------------------|
| **Mean**            | **±SD**           |
| 19.857              | 11.500            |
| 162.393             | 69.186            |
| 43.44               | 11.71             |
Table 4.
Raw Data for Maximal Horizontal Bat Velocity Swing Trials.

| Subject # | Baseline AVG | Post 1 min | Post 2 min | Post 4 min | Post 6 min | Post 8 min | Post 10 min | Post 12 min |
|-----------|--------------|------------|------------|------------|------------|------------|-------------|-------------|
| 1         | 25.761       | 24.001     | 25.246     | 23.908     | 24.779     | 25.194     | 23.486      | 23.520      |
| 2         | 23.583       | 22.189     | 22.837     | 23.467     | 24.461     | 25.191     | 23.366      | 24.095      |
| 3         | 25.055       | 25.191     | 24.096     | 26.194     | 25.191     | 25.366     | 24.095      | 25.175      |
| 4         | 23.206       | 21.543     | 23.347     | 22.204     | 22.780     | 21.792     | 23.164      | 23.164      |
| 5         | 24.360       | 26.644     | 28.519     | 24.812     | 29.032     | 25.533     | 24.073      | 25.715      |
| 6         | 27.821       | 26.057     | 28.919     | 26.623     | 28.557     | 26.178     | 27.620      | 26.430      |
| 7         | 23.424       | 22.167     | 22.501     | 22.581     | 25.726     | 22.606     | 22.825      | 22.825      |
| 8         | 29.293       | 30.149     | 28.915     | 31.066     | 32.297     | 27.980     | 27.989      | 32.789      |
| 9         | 27.448       | 25.626     | 26.079     | 28.155     | 25.908     | 27.808     | 28.578      | 28.578      |
| 10        | 26.372       | 27.450     | 25.578     | 28.635     | 29.806     | 29.013     | 29.807      | 29.012      |
| 11        | 30.005       | 29.554     | 31.276     | 30.655     | 31.165     | 31.967     | 31.644      | 31.860      |
| 12        | 27.184       | 29.741     | 28.328     | 25.739     | 26.914     | 26.578     | 24.252      | 25.958      |
| 13        | 21.900       | 21.092     | 21.907     | 21.155     | 21.673     | 22.052     | 22.744      | 21.834      |
| 14        | 24.761       | 24.107     | 25.306     | 25.897     | 26.825     | 27.008     | 25.121      | 25.530      |
| 15        | 22.583       | 22.134     | 22.357     | 23.997     | 24.908     | 24.019     | 25.190      | 23.006      |
| 16        | 24.855       | 24.791     | 24.126     | 24.063     | 26.102     | 25.041     | 25.271      | 23.995      |
| 17        | 23.106       | 21.846     | 23.347     | 24.207     | 23.780     | 24.792     | 23.590      | 23.664      |
| 18        | 24.160       | 26.734     | 28.519     | 25.912     | 27.032     | 25.123     | 25.093      | 23.995      |
| 19        | 26.921       | 26.127     | 29.019     | 26.902     | 27.127     | 26.368     | 27.620      | 26.430      |
| 20        | 21.424       | 22.167     | 20.501     | 22.391     | 22.726     | 22.099     | 23.526      | 22.915      |
| 21        | 29.193       | 30.249     | 28.915     | 31.029     | 31.797     | 29.910     | 28.280      | 29.919      |
| 22        | 27.348       | 25.626     | 25.979     | 28.155     | 25.892     | 28.770     | 27.818      | 28.118      |
| 23        | 26.322       | 27.230     | 25.578     | 28.725     | 28.856     | 29.013     | 29.667      | 28.988      |
| 24        | 28.105       | 29.554     | 30.206     | 29.975     | 30.961     | 32.013     | 30.655      | 30.222      |
| 25        | 29.184       | 29.741     | 28.328     | 27.739     | 27.914     | 31.078     | 28.252      | 29.058      |
| 26        | 20.910       | 20.918     | 21.627     | 21.625     | 21.778     | 21.952     | 22.044      | 22.734      |
| 27        | 26.352       | 23.011     | 28.611     | 23.246     | 29.046     | 29.505     | 28.611      | 26.011      |
| 28        | 29.993       | 27.149     | 27.915     | 30.016     | 30.197     | 29.980     | 28.999      | 30.089      |

Mean: 25.737
±SD: 2.648

Maximal Horizontal Bat Velocity (m/s)
Effect of a High-Intensity Isometric Potentiating Warm-Up on Bat Velocity
Appendix G

Statistical Analysis Tables

Table 5.  
*Within-Subjects Factors.*

| Measure: Bat_Velocity | Time  | Dependent Variable |
|----------------------|-------|--------------------|
|                      | 1     | Baseline           |
|                      | 2     | Post1min           |
|                      | 3     | Post2min           |
|                      | 4     | Post4min           |
|                      | 5     | Post6min           |
|                      | 6     | Post8min           |
|                      | 7     | Post10min          |
|                      | 8     | Post12min          |

Table 6.  
*Mauchly's Test of Sphericity.*

| Measure: Bat_Velocity | Within Subjects Effect | Mauchly's W | Approx. Chi-Square | df | Sig. | Epsilon<sup>b</sup> |
|----------------------|------------------------|-------------|-------------------|----|------|-------------------|
|                      | Time                   | .210        | 38.118            | 27 | .079 | .674              |

Table 7.  
*Mauchly’s Test of Sphericity continued.*

| Measure: Bat_Velocity | Within Subjects Effect | Epsilon |
|----------------------|------------------------|---------|
|                      |                        | Epsilon |
|                      |                        | Huynh-Feldt | Lower-bound |
|                      | Time                   | .835    | .143     |

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.<sup>a</sup>

a. Design: Intercept

Within Subjects Design: Time

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.
Table 8.
*Tests of Within-Subjects Effects.*

| Measure: Bat Velocity |
|-----------------------|
| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
| --- | --- | --- | --- | --- | --- |
| Time | Sphericity Assumed | 44.733 | 7 | 6.390 | 4.490 | .000 |
| | Greenhouse-Geisser | 44.733 | 4.721 | 9.475 | 4.490 | .001 |
| | Huynh-Feldt | 44.733 | 5.844 | 7.655 | 4.490 | .000 |
| | Lower-bound | 44.733 | 1.000 | 44.733 | 4.490 | .043 |
| Error(Time) | Sphericity Assumed | 268.985 | 189 | 1.423 | 268.985 | 127.467 | 2.110 |
| | Greenhouse-Geisser | 268.985 | 127.467 | 2.110 | 268.985 | 157.775 | 1.705 |
| | Huynh-Feldt | 268.985 | 157.775 | 1.705 | 268.985 | 27.000 | 9.962 |

Table 9.
*Tests of Within-Subjects Effects continued.*

| Measure: Bat Velocity |
|-----------------------|
| Source | Partial Eta Squared | Noncent. Parameter | Observed Power |
| --- | --- | --- | --- |
| Time | Sphericity Assumed | .143 | 31.431 | .992 |
| | Greenhouse-Geisser | .143 | 21.198 | .959 |
| | Huynh-Feldt | .143 | 26.238 | .982 |
| | Lower-bound | .143 | 4.490 | .533 |
| Error(Time) | Sphericity Assumed | 268.985 | 127.467 | 2.110 |
| | Greenhouse-Geisser | 268.985 | 157.775 | 1.705 |
| | Huynh-Feldt | 268.985 | 27.000 | 9.962 |
| | Lower-bound | 268.985 | 127.467 | 2.110 |
| a. Computed using alpha = .05 |
Table 10.

*Tests of Within-Subjects Contrasts.*

Measure: Bat_Velocity

| Source      | Time | Type III Sum of Squares | df | Mean Square | F     | Sig. |
|-------------|------|--------------------------|----|-------------|-------|------|
| Linear      |      | 17.375                   | 1  | 17.375      | 8.711 | .006 |
| Quadratic   |      | 9.254                    | 1  | 9.254       | 8.792 | .006 |
| Cubic       |      | 6.252                    | 1  | 6.252       | 3.791 | .062 |
| Time        | Order 4 | 5.209                  | 1  | 5.209       | 5.220 | .030 |
|             | Order 5 | .699                     | 1  | .699        | .602  | .445 |
|             | Order 6 | .019                     | 1  | .019        | .014  | .908 |
|             | Order 7 | 5.924                   | 1  | 5.924       | 3.535 | .071 |
| Linear      |      | 53.852                   | 27 | 1.995       |       |      |
| Quadratic   |      | 28.420                   | 27 | 1.053       |       |      |
| Cubic       |      | 44.533                   | 27 | 1.649       |       |      |
| Error(Time) | Order 4 | 26.944                 | 27 | .998        |       |      |
|             | Order 5 | 31.324                 | 27 | 1.160       |       |      |
|             | Order 6 | 38.662                 | 27 | 1.432       |       |      |
|             | Order 7 | 45.250                 | 27 | 1.676       |       |      |

Table 11.

*Tests of Within-Subjects Contrasts continued.*

Measure: Bat_Velocity

| Source      | Time | Partial Eta Squared | Noncent. Parameter | Observed Power |
|-------------|------|---------------------|--------------------|----------------|
| Linear      |      | .244                | 8.711              | .812           |
| Quadratic   |      | .246                | 8.792              | .815           |
| Cubic       |      | .123                | 3.791              | .467           |
| Time        | Order 4 | .162                | 5.220              | .596           |
|             | Order 5 | .022                | .602               | .116           |
|             | Order 6 | .001                | .014               | .051           |
|             | Order 7 | .116                | 3.535              | .442           |

a. Computed using alpha = .05
Table 12.
Pairwise Comparisons of bat velocity at all time points with Bonferroni Correction.

| Pairwise Comparisons | Measure: Bat_Velocity |
|----------------------|-----------------------|
| (I) Time | (J) Time | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval for Difference |
|      |          |                      |          |    | Lower Bound | Upper Bound |
| 2    | 1         | .280                | .293    | 1.000 | -.734        | 1.294 |
| 3    | 1         | -.242               | .302    | 1.000 | -1.287       | .803  |
| 4    | 1         | -.321               | .251    | 1.000 | -1.190       | .547  |
| 1    | 5         | -1.268              | .295    | .006  | -2.291       | -.246 |
| 6    | 1         | -.799               | .279    | .222  | -1.764       | .166  |
| 7    | 1         | -.573               | .288    | 1.000 | -1.572       | .426  |
| 8    | 1         | -.475               | .256    | 1.000 | -1.363       | .413  |
| 1    | 2         | -.280               | .293    | 1.000 | -1.294       | .734  |
| 3    | 2         | -.522               | .323    | 1.000 | -1.643       | .599  |
| 4    | 2         | -.601               | .289    | 1.000 | -1.604       | .401  |
| 2    | 5         | -1.549              | .312    | .001  | -2.629       | -.468 |
| 6    | 2         | -1.079              | .370    | .197  | -2.361       | .203  |
| 7    | 2         | -.853               | .413    | 1.000 | -2.285       | .579  |
| 8    | 2         | -.755               | .316    | .678  | -1.852       | .341  |
| 1    | 3         | .242                | .302    | 1.000 | -.803        | 1.287 |
| 2    | 3         | .522                | .323    | 1.000 | -.599        | 1.643 |
| 4    | 3         | -.080               | .398    | 1.000 | -1.458       | 1.299 |
| 3    | 5         | -1.027              | .310    | .074  | -2.101       | .048  |
| 6    | 3         | -.557               | .368    | 1.000 | -1.833       | .719  |
| 7    | 3         | -.331               | .404    | 1.000 | -1.730       | 1.068 |
| 8    | 3         | -.233               | .398    | 1.000 | -1.614       | 1.147 |
| 1    | 4         | .321                | .251    | 1.000 | -.547        | 1.190 |
| 2    | 4         | .601                | .289    | 1.000 | -.401        | 1.604 |
| 3    | 4         | -.080               | .398    | 1.000 | -1.299       | 1.458 |
| 5    | 4         | -.947               | .301    | .113  | -1.991       | .097  |
| 6    | 4         | -.477               | .316    | 1.000 | -1.573       | .618  |
| 7    | 4         | -.252               | .310    | 1.000 | -1.325       | .822  |
| 8    | 4         | -.154               | .203    | 1.000 | -.859        | .551  |
|   | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  |
|---|----|----|----|----|----|----|----|----|
| 1 | 1.268 | .549 | 1.027 | .947 | .470 | .695 | .793 | .947 |
| 2 | .295 | .312 | .310 | .301 | .316 | .348 | .314 | .316 |
| 3 | .006 | .001 | .074 | .113 | 1.000 | 1.000 | .492 | 1.000 |
| 4 | .246 | .468 | -.048 | -.097 | -.625 | -.509 | -.294 | -.618 |
| 5 | 2.291 | 2.629 | 2.101 | 1.991 | 1.564 | 1.900 | 1.880 | 1.325 |
| 6 | .312 | .310 | .001 | .006 | 1.000 | 1.000 | .492 | 1.000 |
| 7 | .006 | .246 | -.294 | -.618 | 1.900 | 1.900 | 1.880 | 1.325 |
| 8 | .246 | .468 | -.048 | -.097 | -.625 | -.509 | -.294 | -.618 |

Based on estimated marginal means

* The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.
Table 13. Correlations between ABS bench, ABS squat, REL bench, REL squat, and degree of potentiation at six minutes post-isometric-warm-up.

|                | ABS_Bench         | ABS_Squat         | REL_Bench         | REL_Squat         | SixMin_CS       |
|----------------|-------------------|-------------------|-------------------|-------------------|-----------------|
| **Correlations** | **ABS_Bench**     | **ABS_Squat**     | **REL_Bench**     | **REL_Squat**     | **SixMin_CS**   |
| Pearson Correlation | 1                | .641**             | .501**             | .058             | .025            |
| Sig. (2-tailed)   |                   | .000              | .007              | .770             | .899            |
| Sum of Squares and Cross-products | 1305.924 | 1409.687 | 8.482 | 1.868 | 7.355 |
| Covariance       | 48.368            | 52.211            | .314              | .069             | .272            |
| N               | 28                | 28                | 28                | 28               | 28              |
| **Correlations** | **ABS_Squat**     |                    |                   |                   |                 |
| Pearson Correlation | .641**             | 1                  | .279              | .554**           | .040            |
| Sig. (2-tailed)   | .000              | .150              | .002              | .841             |                 |
| Sum of Squares and Cross-products | 1409.687 | 3700.082 | 7.956 | 30.199 | 19.554 |
| Covariance       | 52.211            | 137.040           | .295              | 1.118            | .724            |
| N               | 28                | 28                | 28                | 28               | 28              |
| **Correlations** | **REL_Bench**     |                    |                   |                   |                 |
| Pearson Correlation | .501**             | .279              | 1                 | .620**           | -.096           |
| Sig. (2-tailed)   | .007              | .150              | .000              | .628             |                 |
| Sum of Squares and Cross-products | 8.482 | 7.956 | .219 | .260 | -.364 |
| Covariance       | .314              | .295              | .008              | .010             | -.013           |
| N               | 28                | 28                | 28                | 28               | 28              |
| **Correlations** | **REL_Squat**     |                    |                   |                   |                 |
| Pearson Correlation | .058             | .554**             | .620**             | 1                | -.070           |
| Sig. (2-tailed)   | .770              | .002              | .000              | .722             |                 |
| Sum of Squares and Cross-products | 1.868 | 30.199 | .260 | .802 | -.512 |
| Covariance       | .069              | 1.118             | .010              | .030             | -.019           |
| N               | 28                | 28                | 28                | 28               | 28              |
| **Correlations** | **SixMin_CS**     |                    |                   |                   |                 |
| Pearson Correlation | .025             | .040              | -.096             | -.070             | 1               |
| Sig. (2-tailed)   | .899              | .841              | .628              | .722             |                 |
| Sum of Squares and Cross-products | 7.355 | 19.554 | -.364 | -.512 | 65.881 |
| Covariance       | .272              | .724              | -.013             | -.019            | 2.440           |
| N               | 28                | 28                | 28                | 28               | 28              |

**. Correlation is significant at the 0.01 level (2-tailed).