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The Effect of Various Body Positions on Performance of the Isometric Mid-Thigh Pull

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The Effect of Various Body Positions on Performance of the Isometric Mid-Thigh Pull

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A dissertation

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Of the requirements for the degree of

Doctor of Philosophy in Sports Physiology and Performance

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by

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ABSTRACT

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The purpose of this dissertation was to evaluate the effects of changing body position on the execution of the isometric mid-thigh pull (IMTP). Furthermore, while there is evidence to suggest that there is an effect of familiarization on performance of maximal strength tests, there has been no known research evaluating the effect of learning on the IMTP. The effect of familiarization was assessed by evaluating changes in variables obtained from the IMTP. Subjects did not statistically improve over the five IMTP testing sessions, regardless of the body position used, or if subjects had previous experience with weightlifting derivatives. This may indicate that little familiarization is needed for subjects to perform the IMTP before acute increases due to learning stabilize. When body positions were compared, there were differences in force production whether subjects had or did not have experience with weightlifting movements. The magnitude of difference between body position was affected by weightlifting movement experience; lifters with >6 months experience with weightlifting had larger differences in force production between position. Average muscle activation for a variety of muscles, evaluated with surface EMG, appeared to differ between body positions, although these positions are idiosyncratic to experience level. In particular, lumbar erector spinae activation was higher in the bent position for both groups, which may have implications for low back injury risk.In entirety, it appears that if maximizing force production is the goal, the upright positon is optimal. Furthermore, the differing body positions have meaningfully different effects on how

much individual muscles are activated between positions. Lastly, substantial familiarization does not appear to be necessary before subjects perform the IMTP.

DEDICATION

This dissertation is dedicated to the people who have supported me through my academic career. To my wife, who was a constant source of encouragement and support, and who so happily joined me on this grand adventure. To my parents, who supported my endeavors in college, and who supported my idea to go to graduate school, even if they (and I) didn't know quite what I was getting myself into. And lastly, to all of my teachers, coaches, and mentors, who have encouraged and guided me along the way.

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CHAPTER 1

INTRODUCTION

A great deal of an athlete's success can be traced to their physical capacity. In sports where success is built upon an athletes' ability to accomplish a task quickly, there are a certain specific qualities that are closely associated with their ability to do so. (Stone, Stone, & Sands, 2007)

Maximal strength is the quality that describes the highest amount of force that a person is able to generate in a given task, assuming that the time to generate said force is not limited. Maximal strength is a base-level characteristic, one which has substantial relationship to other qualities that are related to force production (Cormie, McGuigan, & Newton, 2011; Haff et al., 1997; Kraska et al., 2009). The quality of explosiveness, or the ability to generate high forces very quickly (i.e. rate of force development), is also closely related to one's maximal strength (Beckham et al., 2013). It is the ability to generate high forces quickly that determine one's effectiveness in a variety of tasks. How effectively an athlete is able to put a shot, swing a baseball bat, and accelerate from the blocks is dependent on how quickly the athlete can develop force against the ground and the implement. Force is directly related to the acceleration imparted to an object of a given mass, thus the more quickly an athlete can generate force, the greater the acceleration that can imparted into said object in a given instant. The total amount of time an athlete has to apply force either to the ground or an implement is generally limited, depending on the task, so the more quickly the athlete can generate force, the greater the impulse the athlete is able to apply, and the higher the resultant momentum.

Given the importance of maximal strength and rate of force development, it behooves the coach to ensure that athletes both possesses adequate levels of these characteristics and are improving them over time through properly applied training. Within this context, an effective test is one that is able to accurately and efficiently provide information about these characteristics to both the coach and athlete. Said test should provide information that allow for normative comparison for assessment and talent identification, ensuring that an athlete performs well relative to her peers, but also to check that the athlete is improving in ways that will transfer to on-field performance.

It is therefore the purpose of this dissertation to evaluate one particular performance test, the isometric mid-thigh pull, which may provide insight into the underlying characteristics of strength-power performance.

CHAPTER 2

REVIEW OF THE LITERATURE

Isometric Testing

Isometric testing, both single and multi-joint, dates back to at least the 1960's (See Chaffin, 1975 for a review). Multi-joint isometric testing was used as a means of evaluating workplace-specific physical preparation in military research (Caldwell et al., 1974; Chaffin, 1975; Churchill, Churchill, McConville, & White, 1977; Knapik, Vogel, & Wright, 1981; Laubach, 1976; Teves, Wright, & Vogel, 1985). Multi-joint isometric tests, with some modification for safety (Knapik et al., 1981) were useful in evaluating preparation for job-related lifting tasks (Knapik et al., 1981; Teves et al., 1985; Vogel, 1986).

Open chain and single joint tests of isometric strength were and are used in many studies within the field of exercise and sport science (e.g. Bemben, Massey, Boileau, & Misner, 1992; Graves, Pollock, Jones, Colvin, & Leggett, 1989; Häkkinen & Komi, 1981; Thorstensson, Sjodin, & Karlsson, 1975), however, the efficacy of isometric testing for dynamic performance has been called into question upon observing that certain isometric testing is a poor predictor of dynamic performance (Wilson & Murphy, 1996). Researchers had observed weak relationships between single-joint isometric tasks and multi-joint dynamic tasks, such as squatting performance (Baker, Wilson, & Carlyon, 1994) and bench press performance (Wilson, Murphy, & Walshe, 1996), and generally concluded that isometric testing was ineffective for drawing conclusions about dynamic tasks (Wilson & Murphy, 1996). These and later studies have shown that the validity of isometric testing likely depends on joint angle specificity (Murphy & Wilson, 1996; Murphy, Wilson, Pryor, & Newton, 1995) and load/force specificity (Kawamori et al., 2006; Murphy & Wilson, 1996). While other factors such as open- versus closed-chain tests and posture have not been specifically tested within this context, each are probably important to the validity of isometric testing given that they are also important aspects of specificity (Murphy & Wilson, 1997; Wilson et al., 1996).

Interestingly, around the same time as the aforementioned studies (Baker et al., 1994; Wilson & Murphy, 1996; Wilson et al., 1996), another research group had published studies purporting the usefulness of compound multi-joint exercises. One group (Young, 1995; Young, McLean, & Ardagna, 1995) purported the usefulness of the isometric squat, measured standing on a force plate against an immoveable bar with a knee angle of 120°. Not long after the studies published by Young et al. (1995), the isometric mid-thigh pull test was described in the literature for the first time (Haff et al., 1997). Both the isometric squat and isometric mid-thigh pull displayed moderate to large correlations between variables measured in the isometric tests, and variables measured during a sprint (Young, 1995), and 1-RMs for the snatch and clean and jerk (Haff et al., 1997). While the isometric squat was used in a few studies through the 1990s and 2000s (Blazevich, Gill, & Newton, 2002; Cormie, Deane, Triplett, & McBride, 2006; McBride, Cormie, & Deane, 2006; Nuzzo, McBride, Cormie, & McCaulley, 2008; Young, 1995; Young et al., 1995), there was increasing use of the isometric mid-thigh pull throughout the same period (Haff et al., 2005; Haff et al., 2008; Kawamori et al., 2006; Kraska et al., 2009; McGuigan, Newton, & Winchester, 2008; McGuigan, Newton, Winchester, & Nelson, 2010; McGuigan & Winchester, 2008; McGuigan, Winchester, & Erickson, 2006; Stone et al., 2003; Stone et al., 2004; Stone et al., 2005; Stone, Sands, Pierce, Ramsey, & Haff, 2008).

Since then the first published paper, the isometric mid-thigh pull has been thoroughly vetted in its ability to relate to dynamic performance (Beckham et al., 2013; Haff et al., 1997; Kawamori et al., 2006; Khamoui et al., 2011; Leary et al., 2012; McGuigan et al., 2010;

McGuigan & Winchester, 2008; McGuigan et al., 2006; Nuzzo et al., 2008; Spiteri et al., 2014; Stone et al., 2004; West et al., 2011). For example, IMTP variables have been found to be correlated to 1-RM squat (McGuigan & Winchester, 2008; McGuigan et al., 2006), 1-RM clean, snatch and derivatives (Beckham et al., 2013; Haff et al., 2005; Haff et al., 1997; Kawamori et al., 2006; Stone et al., 2005), static jumps (Kraska et al., 2009), and countermovement jumps (Khamoui et al., 2011; Kraska et al., 2009).

There have been a number of areas of disagreement between researchers, which have yet to be fully evaluated. In particular, one area of disagreement lies in the precise positioning of the body relative to the bar. Angles used for studies can be found in *Table 2.1*. According to the authors in the original 1997 paper, the IMTP was to be performed in a position similar to the second pull of the clean (Haff et al., 1997). The second pull phase has the highest forces and power outputs of the clean, thus the position was chosen to maximize the possible force and rate of force development of participants performing the IMTP (Haff et al., 1997). Later papers from the same research group and groups associated with the research group, utilized similar body positions or increased the acuity of the knee angle (Beckham et al., 2013; Beckham et al., 2012; Haff et al., 2005; Kraska et al., 2009; Stone et al., 2004; Stone et al., 2005; Stone et al., 2008).

Table 2.1: Knee and hip angles used in IMTP Literature

Reference	Knee angle	Hip angle
Bailey, Sato, Alexander, Chiang, and Stone (2013)	125±5°	175±5°
Beckham et al. (2013)	125-135°	175°
Beckham et al. (2012)	IMTP: NR Lockout: "position corresponding to one that would be achieved in a deadlift".	IMTP: NR Lockout: "position corresponding to one that would be achieved in a deadlift".
Beckham, Suchomel, Bailey, Sole, and Grazer (2014)	125±5°	NR
Comfort, Jones, McMahon, and Newton (2015)	120°, 130°, 140°, 150°, "self-selected"	125°, 145°, "self-selected"
Cormie, McCaulley, Triplett, and McBride (2007)	140°	NR
Crewther et al. (2012)	"similar to second pull of a power clean… shoulders in line with the bar"	"similar to second pull of a power clean… shoulders in line with the bar"
Darrall-Jones, Jones, and Till (2015)	120-130°	"upright trunk"
Haff et al. (2005)	127-145°, based on positions hit in clean	NR, based on positions hit in clean
Haff et al. (2008)	127-145°, based on positions hit in clean	NR, based on positions hit in clean
Haff, Ruben, Lider, Twine, and Cormie (2015)	137.6±12.9°	140.0±6.6°
Haff et al. (1997)	144±5°	145±3°
Hornsby et al. (2013)	NR	NR
Kawamori et al. (2006)	141±10°	124±11°
Khamoui et al. (2011)	127-145°	NR
Kraska et al. (2009)	120-135°	170-175°
Leary et al. (2012)	142±7°	146±11°
Lawton, Cronin, and McGuigan (2012)	NR, "bar at height of knee"	NR, "bar at height of knee"

Table 2.1 continued

McGuigan et al. (2008)	130°	NR
McGuigan et al. (2010)	130°	NR
McGuigan and Winchester (2008)	130°	NR
McGuigan et al. (2006)	130°	NR
Nuzzo et al. (2008)	140° “bar was positioned just below the crease of the hip”	NR “bar was positioned just below the crease of the hip”
Painter et al. (2012)	NR	NR
Sapstead and Duncan (2013)	130°	NR
Sato et al. (2012)	125±5°	175±5°
Secomb et al. (2015)	125-140° “shoulders placed over the bar… similar to the second pull of a power clean”	NR “shoulders placed over the bar… similar to the second pull of a power clean”
Spiteri et al. (2014)	140°	140°
Stone et al. (2003)	135-145°	155-165°
Stone et al. (2005)	NR “optimal position of…initiation of second pull in a clean”	NR “optimal position of…initiation of second pull in a clean”
Stone et al. (2004)	140-145	"near vertical trunk"
Stone et al. (2008)	120-135°	170-175°
Teo, McGuigan, and Newton (2011)	130°	NR
Thomas, Comfort, Chiang, and Jones (2015)	“self-selected”	“self-selected”
Thomas, Jones, and Comfort (2014)	“self-selected” “bar…just below the crease of the hip”	“self-selected” “bar…just below the crease of the hip”
Thomas, Jones, Rothwell, Chiang, and Comfort (2015)	“self-selected” “bar…just below the crease of the hip”	“self-selected” “bar…just below the crease of the hip”
West et al. (2011)	120-130°	NR "Flat trunk, shoulders in line with bar"
Whittington et al. (2009)	120-135°	170-175
Winchester et al. (2008)	130°	NR

Other groups have used the IMTP, using a similar knee angle of approximately 125-135 degrees, although with a more acute hip angle (McGuigan, 2011; McGuigan et al., 2008), which results in a more bent over body position than used in those reported by other researchers (Haff et al., 2005; Haff et al., 1997; Stone et al., 2005). A very large contingent of literature does not report the knee and/or hip angles used (see *Table 2.1*), which makes determining the actual body position used for the studies difficult. Whether there is a substantive difference between the positions from each "style" of IMTP remains unclear. Only two studies to date have evaluated the effects of varying body position when performing isometric pulls. One study evaluated the effects of varying both hip and knee angle when performing the IMTP (Comfort et al., 2015). Comfort et al. (2015) found that there were no differences in the forces generated against the ground when different body positions (varied knee and hip angles) were used. In contrast, another study found that there was statistically greater force generation in the upright style (knee angle of approximately 125° and hip angle of approximately 145°) versus a "deadlift lockout" style at the same bar height in powerlifters (Beckham et al., 2012). Despite the powerlifters having little to no training experience in the mid-thigh position and substantial experience training the deadlift with lockout exercises, there was still a large effect size ($d = 1.23$). Currently there is not a consensus as to the efficacy of any particular body position.

While it initially appears that there is little difference between the extremes of each position (either upright or bent over) in how both relate to dynamic tests of strength (Beckham et al., 2013; Haff et al., 2005; McGuigan et al., 2010; McGuigan & Winchester, 2008; McGuigan et al., 2006; Stone et al., 2005), but this must be further examined. In addition, the conflicting studies that have evaluated the force production differences between upright and bent positions (Beckham et al., 2012; Comfort et al., 2015) indicate that further research is necessary to glean potential differences in performance between positions. Should there be a difference in the force production capability between positions, the existence and magnitude of difference must be considered when comparing results between studies and using the results for making broader conclusions about performance.

The Effect of Familiarization

To some extent, there will be learning that takes place in performing a novel task. Each trial performed acts as a practice trial to a degree, and thus improvement within a test is sometimes expected. With more difficult or complex tests and motor skills, learning may play a larger role in improvement of the test than with simpler tests. Novices to a particular task are generally expected to improve rapidly as they establish the motor patterns necessary for better performing the task.

Within the realm of sport science, and ideal performance test will reflect the fitness abilities underlying better execution of the test. In an agility test for example, better execution of the test (e.g. lower times), would ideally reflect an increase in the underlying characteristics inherent to agility such as a better ability to negatively accelerate the body, reaccelerate quickly and so on (Sheppard & Young, 2006). A learning or familiarization effect makes assessment of increased performance more difficult, because without isolation of the existence and magnitude of a learning effect, changes over time may be due to better execution of the test, and not necessarily changes in the underlying characteristics of test performance (Stone et al., 2007). While the skill aspect of a performance test is important, the improvement of physical performance characteristics are the main focus of a strength and conditioning coach.

It can be difficult to extricate the motor learning aspects of test execution from the physical performance aspects, however knowledge of the existence and magnitude of a learning effect allows one to evaluate what changes in performance of a test are due to learning aspects, and which are true changes in the athlete’s preparation. Understanding of the existence and magnitude of a learning effect for a given test gives the coach or researcher instruction as to how much familiarization may be necessary to ensure that observed changes after the familiarization period are due to changes in physical characteristics and not simply increased mastery of the task in and of itself.

With strength testing, as with all testing, there is some degree of “learning” involved in improvement of the test (Benton, Swan, & Peterson, 2009; Cronin & Henderson, 2004; McCurdy, Langford, Cline, Doscher, & Hoff, 2004; Ploutz-Snyder & Giamis, 2001). Like other performance tests, gain in strength is somewhat difficult to isolate from increases purely due to skill, especially given that expression of strength has been likened to a skill (Stone et al., 2007). In fact, bouts of strength training show similar changes in the primary motor cortex with transcranial magnetic stimulation as those in motor learning studies (Selvanayagam, Riek, & Carroll, 2011). However, because strength is contextual, and based on the task in which force is produced, it could be argued that a learning effect itself is in and of itself an essential part of increasing strength. Given the important role of intra and inter-muscular coordination and antagonist co-activation to the expression of force in a task (Folland & Williams, 2007), for example, learning and increasing strength are thus inextricably linked.

While changes in strength are somewhat similar to those of motor learning, short-term changes in lower body maximal strength generally attributable to a learning effect have been observed in numerous tests of maximal strength. These improvements have been observed in both upper and lower-body tests, but some evidence suggests that rates of learning differ between upper and lower body (Seo et al., 2012), thus the following discussion is limited to lower-body 1-RMs.

McCurdy et al. (2004) observed improvements in trained and untrained men and women in unilateral 1-RM and 3-RM over 48 hours, but not in a third trial in a unilateral lower-body exercise. Benton et al. (2009) found that leg press 1-RMs separated by 24 hours had not yet stabilized after 3 sessions. Ploutz-Snyder and Giamis (2001) found that young and old untrained women needed 3.6±0.6 sessions and 8.8±0.6 sessions separated by at least 48 hours for 1-RM knee extension to stabilize. Cronin and Henderson (2004) observed increases in 1-RM supine squat tested once per week for four weeks in untrained men. Schroeder et al. (2007) evaluated 1-RMs for the leg press, leg curl, and leg extension exercises on two occasions 7-10 days apart, but only observed changes in the knee extension exercise between the two sessions.

In studies with multiple testing bouts, there is undoubtedly a training stimulus involved. In untrained participants, it seems likely that performing a maximal strength testing protocol is a greater overload for the untrained participants than for the trained participants, which may result in a greater training stimulus. However, the study by McCurdy et al. (2004) observed similar trends in 1-RM stability between trained and untrained participants over three trials, so this is unclear. It is also possible that age may play a role in the changes (or lack thereof) observed in these studies. Ploutz-Snyder and Giamis (2001) observed that a greater number of sessions were needed for older women for 1-RMs to stabilize. However, Cronin and Henderson (2004) observed that 1-RMs improved over 4 weeks, while Schroeder et al. (2007) did not, despite having older subjects than the prior study.

Because testing may serve as a training stimulus, ideally a learning effect would be assessed prior to training adaptation taking place. However, this must be balanced by the fatigue generated in performing the test, as fatigue from the test may mask a learning effect that may have taken place, similar to the trend described by the fitness-fatigue model of training. Some studies have evaluated maximal strength tests within the day to address these issues.

McGarvey, Morrey, Askew, and An (1984) evaluated a variety of upper body joint actions isometrically at three times during the same day. With some tests, they observed increases from the earlier parts of the day to the later, but not other tests. Furthermore, given diurnal variations in performance (Sedliak, Finni, Cheng, Haikarainen, & Häkkinen, 2008), it is difficult to draw strong conclusions from this study. Another study, with perhaps the strongest application to the isometric mid-thigh pull, is a study by Pekünlü and Özsu (2014), which observed that resistance trained males continued increasing their peak force with subsequent trials, with most participants requiring greater than 8 trials before force output had stabilized. The finding by Pekünlü and Özsu (2014), in light of the mixed results of all other studies that have evaluated a learning effect in a strength test, indicates a real need for evaluating the effect of learning on the IMTP.

CHAPTER 3

THE EFFECT OF FAMILIARIZATION ON PERFORMANCE OF THE ISOMETRIC MID-THIGH PULL

Abstract

While the isometric mid-thigh pull (IMTP) has been used often in the literature, the effects of familiarization on kinetic variables of the pull has not been determined. We measured performance of two positions of the IMTP over 5 days of familiarization and testing. Subjects were drawn from two populations, experience with weightlifting derivatives (>6 months of regular use) and little experience with weightlifting derivatives (<3 months of use). Peak force, force at 90ms, force at 250ms, and impulse 0-250ms were compared used multiple mixed-design ANOVAs. The effect of familiarization was not statistically significant as a main effect or as part of an interaction effect. This indicates that only small amounts of familiarization (the warmups used prior to the first pull (2 repetitions of 50% effort, 2 repetitions of 75% effort) were sufficient for familiarizing subjects both experienced and inexperienced with weightlifting derivatives.

Keywords: learning effect, test-retest, maximal strength, rate of force development

Formatted for: *Journal of Strength and Conditioning Research*

Introduction

The isometric mid-thigh pull (IMTP) is a commonly used test of various aspects of strength. There is growing use of the IMTP by researchers and practitioners due to its efficiency, ease of use, and variety of useful measures of performance (12). Variables typically analyzed with the IMTP have been shown to have strong relationships to a variety of dynamic measures of performance, such as lower body 1-RMs (18-20), snatch and clean and jerk performance (2, 9, 25), and static and countermovement vertical jump performance (14). Despite its common use, there is no current literature reporting the assessment of the amount of familiarization necessary to elicit a maximum performance.

Familiarization is an important consideration for any aspect of performance testing, given that the interpretation of results and changes in results over time are expected to reflect true change in the athletes' performance, not simply improved ability to do the test. The test itself is unimportant, rather it is the underlying abilities the test reflects that are of interest. Some literature has evaluated the effect of learning and familiarization on 1-RM performance (5, 8, 15, 22, 23), indicating that multiple 1-RM trials in different sessions may be necessary for subjects to be sufficiently familiarized, and for performance to stop acutely increasing. One study evaluated acute learning effects in the isometric squat (21) a similar test to the IMTP, and found that with resistance-trained men and women, 8-10 trials were necessary to elicit a maximum performance.

In research and in practice, the IMTP has been used in various populations, each with various levels of training (3, 7, 14, 16, 17). Furthermore, multiple body positions have been used for executing the IMTP, roughly grouped into more "upright" and "bent" positions. While force production differences have been assessed between body positions (3, 7), little else has been evaluated between the two positions. Therefore, the purpose of the present study was to evaluate the effect of familiarization on execution of the IMTP while considering the potential influence of both weightlifting experience (<6 months experience or >6 months experience) and body position of the pull on familiarization.

Methods

Experimental Approach to the Problem

Subjects came into the laboratory on 5 different occasions to perform pulls. Each session was separated by 72-96 hours to allow for sufficient rest. In between sessions subjects were provided with a standard training program of low volume and moderate intensity to be performed no closer than 48 hours to the next session. The bar heights, joint angles, and foot placement were measured on the first session; these same parameters were used in all subsequent sessions. After measurement, subjects completed a standard warmup that would be used on all subsequent sessions (2 minutes cycling at 50 watts, 50-60 RPM, 6 repetitions each of forward walking lunges, reverse walking lunges, side lunges, straight leg march, and quadriceps pulls, then 5 bodyweight squats and 5 ballistic bodyweight squats). This warmup is different than that used in previous literature (e.g. 12, 19); we specifically chose a general warmup so as not to benefit one particular pulling position over the other. After the standard warmup, subjects completed the IMTP in one of two positions, assigned in random order for each session, as outlined below. A full outline of sessions can be found in Figure 3.1.

Sessions 1, 3 and 5 were considered “familiarization sessions” due to the shortened pull phase. Sessions 2 and 5 were considered “testing sessions”, so that a relatively un-familiarized state (session 2) could be compared with a substantially familiarized state. Sessions 2 and 5 used slightly different testing batteries than sessions 1, 3, and 5. On sessions 2 and 5, subjects pulled for 5 seconds in each 100% trial. 5 second long pulls were limited to sessions 2 and 5 as previous use of this test and pilot testing indicated that 2.5 seconds was far less fatiguing than 5 second pulls, yet still allowed subjects to practice application of maximal force and rate of force development.

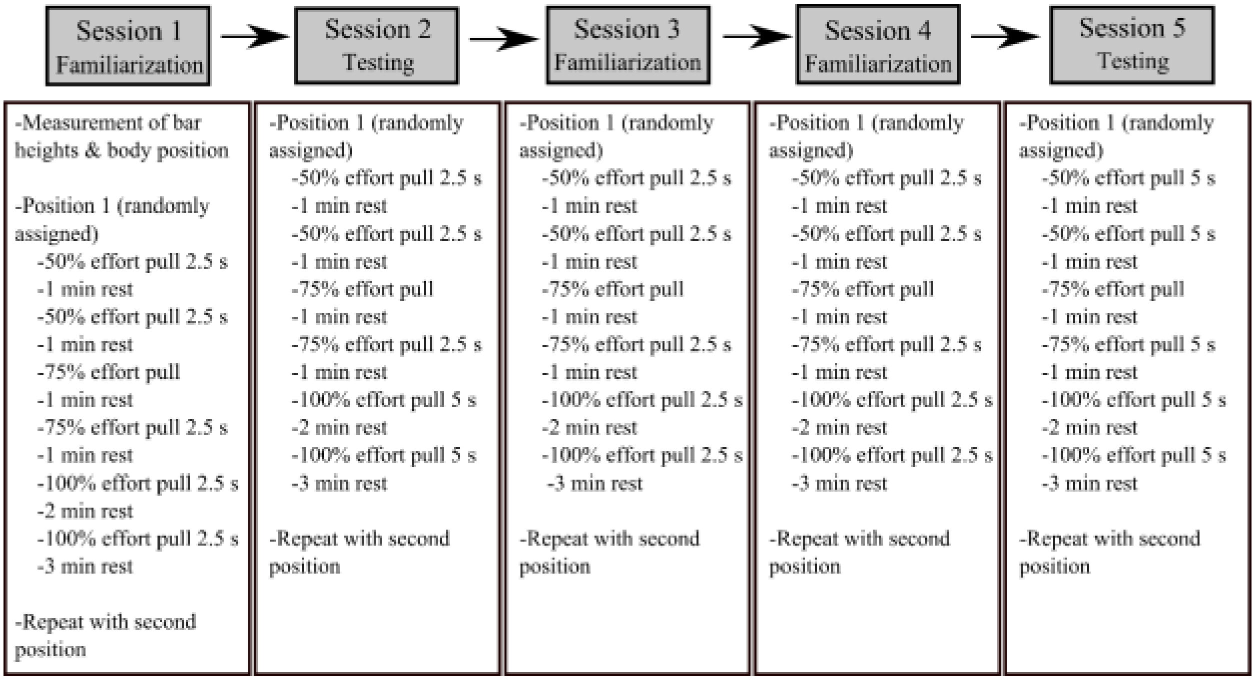

Figure 3.1: Overview of Each Session

Subjects

Subjects participating in the study were either recreationally active males with less than 6 months of experience with weightlifting movements (n=10, body weight: 75.1±11.5kg, years of weightlifting: 0.09±0.09y range: 0-0.24y) or weightlifting-trained males with greater than 6 months of weightlifting experience (n=12, body weight: 84.4±7.4kg, years of weightlifting: 4.9±4.2y range: 1.07-13.5y). All subjects were free of injury for 6 months prior, and had not performed the IMTP prior to the study. Prior to the first testing session, subjects were informed of study processes, and gave their written attestation of informed consent. Study procedures were approved by the university Institutional Review Board.

Isometric Mid-Thigh Pulls

Subjects performed the IMTP in two different body positions. The first position, or "upright" position, was performed with approximately 125° knee and 145° hip angles. The second position, or "bent" position, was performed with a 125° knee angle and a 125° hip angle. Each body position represents two positions for the IMTP commonly used in the literature (2, 3, 10, 13, 14, 16, 18, 19, 25). In each testing session, IMTP order was randomized between the two positions each day to alleviate fatigue effects.

For each pulling trial, subjects were asked to step onto the force plates and assume the position (bent or upright) to be used. Subjects were told to use a minimal amount of tension in order to remove as much slack from the body as possible prior to initiation of the pull. Subjects received a countdown, then initiated the pull based on the trial (e.g. 50% effort). For 100% effort trials, subjects were instructed to pull "as fast and as hard as you can" to ensure maximal rate of force development in the early parts of the pull (4)

Testing for the IMTP was performed on two parallel force plates (45.5 cm x 91 cm, RoughDeck HP; Rice Lake Weighing Systems in a custom power-rack (Sorinex, Irmo, SC) that allows for fixation of the bar at any height.

Analog data from each force plate were amplified and filtered (low-pass at 16 Hz), and sampled at 1000Hz (DAQCard-6063E, National Instruments). A digital filter (low-pass 10Hz, 2nd order Butterworth) was applied, signals from each force plate were summed, and data were analyzed in custom Labview software (Labview 2010, National Instruments).

Only 100% trials were used for analysis. Variables collected from the force plate were as follows: force at 50ms (F50), force at 90ms (F90), force at 250ms (F250), impulse 0-50ms (IMP50), impulse 0-90ms (IMP90), and impulse (IMP250). Each of these variables is commonly used in literature pertaining to the IMTP. Peak force (PF) was only calculated for sessions 2 and 5, as the 2.5 seconds used on the 100% pulls was not long enough for subjects to reach a force value representative of their maximum strength). Calculated values were averaged between each of the 2 trials for each position within a given session.

Analysis

The within-session test-retest reliability was assessed for each measured variable using the following methods: ICCs with 95% confidence interval, a paired t-test, and CV (typical error of log-transformed data). Reliability was assessed individually for each subset of data (i.e. each position on each testing session). In addition, ICCs and 95% CI were calculated between sessions 2 and 5 to assess between session reliability for all variables. Data were screened for violations of mixed ANOVA assumptions (26).

A three-way mixed repeated measures ANOVA (testing session X position X group) was used to evaluate effects of testing sessions (sessions 2 and 5), IMTP position, and weightlifting experience level on PF. A series of three-way mixed repeated measures ANOVAs (testing session X position X group) was used to evaluate effects of IMTP sessions (sessions 1 through 5), IMTP position, and experience with weightlifting derivatives level on all other variables. Sphericity was tested used Mauchley's test, and in cases where the assumption of sphericity was violated, the Greenhouse-Geisser correction was used. Generalized eta-squared (η_g^2) was used for effect sizes and interpreted with the following scale: 0.02 small, 0.13 medium, and 0.26 large (1, 6).

Results

The variables PF, F90, F250, IMP250 were deemed adequately reliable for later analysis. F50, IMP50, and IMP90 had subgroups with a combination of ICC less than 0.7 (cite) and statistically significant paired t-test between re-test values, and were thus excluded in later analysis (see Table 3.1). ICC values and 95% CIs between sessions were as follows: PF: 0.94, 0.89-0.97; F90: 0.96, 0.95-0.98; F250: 0.98, 0.96-0.99, IMP250: 0.97, 0.95-0.98. IMTP results can be found in Table 3.2. Results from the repeated measures ANOVAs can be found in Table 3.3.

Table 3.1: Reliability results for all subsets of analysis, represented as highest and lowest values observed among all subsets for each variable

	ICC		ICC 95% CI		t-test P-Value		CV	
	Min	Max	Min	Max	Min	Max	Min	Max
PF	0.96	1.00	0.85-0.99	0.99-1	0.08	0.94	1.4%	5.4%
F50	0.38	0.96	0-0.82	0.9-0.94	0.07	0.94	4.4%	13.5%
F90	0.68	0.98	0-0.91	0.93-1	0.11	0.99	4.3%	14.2%
F250	0.79	0.98	0.16-0.95	0.96-0.98	0.053	0.98	3.3%	9.0%
IMP50	0.59	0.96	0-0.88	0.92-0.95	0.03	0.99	4.2%	14.8%
IMP90	0.53	0.97	0-0.86	0.92-0.95	0.06	0.99	4.3%	12.9%
IMP250	0.84	0.99	0.43-0.95	0.95-0.97	0.054	0.97	3.1%	9.2%

PF: peak force, F50: force at 50ms, F90: force at 90ms, F250: force at 250ms, IMP50: impulse 0-50ms, IMP90: impulse 0-90ms, IMP250: impulse 0-250ms.

Table 3.2: PF, F90, F250, and IMP250 Results from IMTPs

		Bent		Upright	
Variable	Session	Experienced	Inexperienced	Experienced	Inexperienced
PF (N)	2	3662.8±662.4	2931.5±555.1	4551.7±785.2	3396.3±585.1
	5	3660.7±612.4	3108.3±677.8	4587.1±981.8	3493.9±568.2
F90 (N)	1	2035.1±273.1	1703.5±551.6	2351.6±413.7	1788.9±421.4
	2	1966.9±323.1	1540±382.5	2352.9±384.4	1726.1±384.2
	3	2057.2±360.8	1702.1±372	2336.5±479	1803.9±452
	4	2149.7±445.4	1607.6±324.4	2434.2±600.1	1693.8±348.9
	5	2058.2±323.5	1592.1±351	2441.2±562	1755.5±399.2
F250 (N)	1	2886.4±414.2	2435.2±471.2	3394±572.8	2560.9±385
	2	2795.1±494.4	2219.8±461.7	3392.2±525.1	2449.1±402.6
	3	2742.7±531.4	2202.3±409.8	3281.4±594.8	2582.3±402
	4	2806.8±591.5	2284.3±354.3	3278.8±725.7	2369.3±255.3
	5	2722.3±425.1	2213.8±349.9	3421.7±688.6	2401.3±349.1
IMP250 (N·S)	1	559.6±72	459±110.8	642.4±107	488.4±91.4
	2	541±84.7	432.9±89.9	649.8±103.2	472.7±83.8
	3	552.4±97.8	454.1±86.8	637.8±119	494.7±100.7
	4	572±115.7	447.7±75.8	657.3±152.7	463.8±73.2
	5	558.2±86.6	435.3±76.3	669.9±144.5	474.4±84.5

PF: peak force, F90: force at 90ms, F250: force at 250ms, IMP250: impulse 0-250ms.

Table 3.3: Results of Repeated Measures ANOVAs

	Main Effects		
Variable	Group	Session	Pull Position
PF	F(1,20) = 10.1 p = 0.005 η_g^2= 0.30	F(1,20) = 1.2, p=0.30 η_g^2=0.002	F(1,20) = 102.7 p<0.001 η_g^2=0.14
F90	F(1,20) = 10.9 p = 0.004 η_g^2= 0.30	F(2.4,48.8) = 1.0 p = 0.40 η_g^2= 0.004	F(1,20) = 86.5 p < 0.001 η_g^2= 0.05
F250	F(1,20) = 13.3 p = 0.002 η_g^2= 0.34	F(2.7,53.8) = 2.3, p=0.09 η_g^2= 0.007	F(1,20) = 94.5 p < 0.001 η_g^2= 0.09
IMP250	F(1,20) = 12.8 p = 0.002 η_g^2= 0.34	F(2.4,47.3) = 0.5, p = 0.64 η_g^2= 0.001	F(1,20) = 85.7 p < 0.001 η_g^2= 0.065

	Interaction Effects			
	Group X Time	Group X Pull Position	Session X Pull Position	Group X Session X Pull Position
PF	F(1,20) = 0.7 p=0.41 η_g^2=0.001	F(1,20) = 13.5 p=0.002 η_g^2=0.02	F(1,20) = 0.03 p= 0.85 η_g^2=0.000	F(1,20) = 0.27, p=0.61 η_g^2=0.000
F90	F(2.4,48.8) = 1.6 p = 0.21 η_g^2= 0.006	F(1,20) = 17.7 p=0.004 η_g^2= 0.011	F(4,80) = 0.90 p = 0.47 η_g^2= 0.002	F(4,80) = 0.04, p = 1.00 η_g^2= 0.000
F250	F(2.7,53.8) = 0.83 p = 0.47 η_g^2= 0.002	F(1,20) = 21.1 p <0.001 η_g^2= 0.02	F(2.5,50.1) = 2.5 p = 0.08 η_g^2= 0.004	F(2.5,50.1) = 1.6 p = 0.21 η_g^2= 0.002
IMP250	F(2.4,47.3) = 1.4 p = 0.25 η_g^2= 0.004	F(1,20) = 20.1 p < 0.001 η_g^2= 0.016	F(4,80) = 1.1 p = 0.39 η_g^2= 0.002	F(4,80) = 0.3 p = 0.86 η_g^2= 0.000

PF: peak force, F90: force at 90ms, F250: force at 250ms, IMP250: impulse 0-250ms.

Discussion

The finding that early force-time variables in certain subsets of pulls were not reliable is not in agreement with previous studies, which have generally shown excellent reliability for early force-time variables (e.g. 50ms, 90ms; 2, 7, 11, 14). The subsets with problematic reliability were only 1 or 2 subsets of 20 total. However, because each subset was of important in the overall analysis, it was prudent to exclude potentially problematic variables. The fact that the problematic subsets were a only small portion of the overall pool of subsets of the variables excluded from the analysis (5 potentially problematic subsets out of 60 total), does not appear to be an indication of that variables in this study were generally problematic with respect to their reliability.

The main findings of the study are that for the variables that met standards of reliability to be used in analysis (PF, F90, F250, and IMP250), there were no statistically significant changes over the five sessions, regardless of pulling position or experience level with weightlifting movements. This would appear to indicate that for subjects with a high amount of experience with weightlifting or low amount, there is no substantial effect of greater familiarization with more trials. There was not a statistically signficant interaction effect between time and pulling position, or time, pulling position, and group, which appears to indicate that a learning effect is not present.

The current findings of a lack of familiarization effect agree with some unpublished work by Stone, O'Bryant and Haff (24), but the findings contrast those of past studies that have observed an effect of familiarization on strength tests in untrained (5, 8, 15, 22) or trained (15) men and women. The present findings agreed with one study that found no familiarity effect for multiple lower body 1-RMs in men and women with 3 months resistance training experience (23). Differences in the training background of subjects may explain some of the difference in findings between the present and past studies, but of the two studies with even somewhat trained subjects, the existence of a familiarization effect is unclear (15, 23).

The findings of the present study also contrast those of a study evaluating resistance trained subjects performing an isometric squat test for the first time (21). Most subjects needed between 8-10 trials to reach a maximum performance in this test (21). In the present study, a much higher number of trials were used in the warm-up protocol, and in total. Two separate positions were used, which doubled the number of warm-up and maximum effort trials used throughout the study. It is possible that in the present study that the high number of trials (over 60 total trials by the end of the study) makes comparison difficult between the present study and the study by Pekünlü and Özsu (21). Furthermore, while force production was different between positions, it is possible that there is a transfer of familiarization between the two positions. If this is the case, performing the bent position was, in effect, practice for the upright position, and vise versa. Further studies should evaluate a specific position to isolate the potential for overlap in familiarization.

Because the goal of the study was to evaluate the effect of familiarization, we used more submaximal trials than used in most other studies. Before commencing 100% pulls in a given position (i.e. bent or upright), subjects performed two 50% effort and two 75% effort pulling trials. Many previous studies have used only one or two submaximal familiarization/warmup IMTP trials (2, 13, 14, 25), so it is possible that subjects were adequately or mostly adequately familiarized by the first 100% trial. Further research should assess the familiarization effect with less warmups to evalute the possibility that only some submaximal trials are necessary for adequate familiarization.

While it was not a primary aim of the study, the effects of group (with or without substantial weightlifting experience) and pulling position (bent or upright), were assessed. There were statistically signficant main effects for group and pulling position, and a statistically signficiant interaction effect (group X pulling position) for all variables tested. This indicates that there are differences in force production between the upright and bent body positions, and that the magnitude of this difference is affected by experience with weightlifting. Force production differences between body position agrees with one previous study that evaluated varying body positions in powerlifters (3), but disagrees with another that evaluated a variety of body positions in resistance trained participants (7).

Conclusion

Within the context of the present study, it does not appear that there is a substantial need for familiarization when performing the isometric mid-thigh pull. Most previous research uses a single familiarization session when measuring bar heights and body positioning; this is likely enough familiarization to expect a maximal performance from subjects, whether those subjects are recreationally trained or experienced with weightlifting derivatives and thus the second pull position.

References

1. Bakeman R. Recommended effect size statistics for repeated measures designs. *Behav Res Methods* 37: 379-384, 2005.
2. Beckham G, Mizuguchi S, Carter C, Sato K, Ramsey M, Lamont H, Hornsby G, Haff G, and Stone M. Relationships of isometric mid-thigh pull variables to weightlifting performance. *J Sports Med Phys Fitness* 53: 573-581, 2013.
3. Beckham GK, Lamont HS, Sato K, Ramsey MW, Haff GG, and Stone MH. Isometric Strength of Powerlifters in Key Positions of the Conventional Deadlift. *J Trainology* 1: 32-35, 2012.
4. Bemben MG, Clasey JL, and Massey BH. The effect of the rate of muscle contraction on the force-time curve parameters of male and female subjects. *Res Q Exerc Sport* 61: 96-99, 1990.
5. Benton MJ, Swan PD, and Peterson MD. Evaluation of multiple one repetition maximum strength trials in untrained women. *J Strength Cond Res* 23: 1503-1507, 2009.
6. Cohen J. *Statistical Power Analysis for the Behavioral Sciences.* New Jersey: Lawrence Erlbaum Association, 1988.
7. Comfort P, Jones PA, McMahon JJ, and Newton R. Effect of knee and trunk angle on kinetic variables during the isometric midthigh pull: test-retest reliability. *Int J Sports Physiol Perform* 10: 58-63, 2015.
8. Cronin JB and Henderson ME. Maximal strength and power assessment in novice weight trainers. *J Strength Cond Res* 18: 48-52, 2004.
9. Haff GG, Carlock JM, Hartman MJ, Kilgore JL, Kawamori N, Jackson JR, Morris RT, Sands WA, and Stone MH. Force-time curve characteristics of dynamic and isometric

muscle actions of elite women olympic weightlifters. *J Strength Cond Res* 19: 741-748, 2005.

10. Haff GG, Jackson JR, Kawamori N, Carlock JM, Hartman MJ, Kilgore JL, Morris RT, Ramsey MW, Sands WA, and Stone MH. Force-time curve characteristics and hormonal alterations during an eleven-week training period in elite women weightlifters. *J Strength Cond Res* 22: 433-446, 2008.

11. Haff GG, Ruben RP, Lider J, Twine C, and Cormie P. A comparison of methods for determining the rate of force development during isometric midthigh clean pulls. *J Strength Cond Res* 29: 386-395, 2015.

12. Haff GG, Stone M, O'Bryant HS, Harman E, Dinan C, Johnson R, and Han K-H. Force-Time Dependent Characteristics of Dynamic and Isometric Muscle Actions. *J Strength Cond Res* 11: 269-272, 1997.

13. Hornsby WG, Haff GG, Sands WA, Ramsey MW, Beckham GK, Stone ME, and Stone MH. Alterations in strength characteristics for isometric and dynamic mid-thigh pulls in collegiate throwers across 11 weeks of training. *Gazz Med Ital* 172: 929-940, 2013.

14. Kraska JM, Ramsey MW, Haff GG, Fethke N, Sands WA, Stone ME, and Stone MH. Relationship between strength characteristics and unweighted and weighted vertical jump height. *Int J Sports Physiol Perform* 4: 461-473, 2009.

15. McCurdy K, Langford GA, Cline AL, Doscher M, and Hoff R. The Reliability of 1- and 3Rm Tests of Unilateral Strength in Trained and Untrained Men and Women. *J Sports Sci Med* 3: 190-196, 2004.

16. McGuigan MR, Newton MJ, and Winchester JB. Use of isometric testing in soccer players. *J Aus Strength Cond Assn* 16: 11-14, 2008.

17. McGuigan MR, Newton MJ, Winchester JB, and Nelson AG. Relationship between isometric and dynamic strength in recreationally trained men. *J Strength Cond Res* 24: 2570-2573, 2010.

18. McGuigan MR and Winchester JB. The relationship between isometric and dynamic strength in college football players. *J Sport Sci & Med* 7: 101-105, 2008.

19. McGuigan MR, Winchester JB, and Erickson T. The importance of isometric maximum strength in college wrestlers. *J Sports Sci Med* 5: 108-113, 2006.

20. Nuzzo JL, McBride JM, Cormie P, and McCaulley GO. Relationship between countermovement jump performance and multijoint isometric and dynamic tests of strength. *J Strength Cond Res* 22: 699-707, 2008.

21. Pekünlü E and Özsu İ. Avoiding Systematic Errors in Isometric Squat-Related Studies without Pre-Familiarization by Using Sufficient Numbers of Trials. *Journal of Human Kinetics* 42: 201-213, 2014.

22. Ploutz-Snyder LL and Giamis EL. Orientation and familiarization to 1RM strength testing in old and young women. *J Strength Cond Res* 15: 519-523, 2001.

23. Seo DI, Kim E, Fahs CA, Rossow L, Young K, Ferguson SL, Thiebaud R, Sherk VD, Loenneke JP, Kim D, Lee MK, Choi KH, Bemben DA, Bemben MG, and So WY. Reliability of the one-repetition maximum test based on muscle group and gender. *J Sports Sci Med* 11: 221-225, 2012.

24. Stone MH, O'Bryant H, and Haff GG. Preliminary investigation of the isometric mid-thigh pull. 1995.

25. Stone MH, Sands WA, Pierce KC, Carlock J, Cardinale M, and Newton RU. Relationship of maximum strength to weightlifting performance. *Med Sci Sports Exerc* 37: 1037-1043, 2005.

26. Tabachnick B and Fidell L. *Experimental Design Using Anova*. Belmont, CA: Duxbury/Thomson, 2007.

CHAPTER 4

THE EFFECT OF BODY POSITION ON FORCE PRODUCTION DURING THE ISOMETRIC MID THIGH PULL

Abstract

Varying body positions have been used in the literature when performing the isometric mid-thigh pull. We evaluated force production in the isometric mid-thigh pull in bent (125° knee and 125° hip angles) and upright (125° knee, 145° hip angle) positions in participants with (>6 months) and without (< 6 months) substantial experience with weightlifting. A mixed-design ANOVA was used to evaluate the effect of pull position and group on peak force, force at 50ms, 90ms, and 250ms, and impulse 0-50ms, 0-90ms, 0-250ms. There were statistically significant main effects for group and pull position for all variables tested, and statistically significant interaction effects for peak force, force at 250ms, and impulse at 250ms. Calculated effect sizes were small to large for all variables in participants with weightlifting experience, and were small to moderate between positions for all variables in participants without weightlifting experience. Results from this study suggest that the position used in the isometric mid-thigh pull directly impacts the force produced during the test. Based on these findings it is essential that the body positions used are standardized and reported in research publication in order to allow for data to be correctly reported. A central finding of the study is that the upright body position (125° knee and 145° hip) should be used given that forces generated are highest in that position. Actual joint angles during maximum effort pulling should be measured to ensure body position is close to the position intended.

Keywords: test validity, maximal strength, explosive strength, performance testing

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Introduction

Maximal strength testing is considered to be a worthwhile method for evaluating athletes.[1] While maximal strength is commonly tested using 1-RMs, other means of evaluating maximal strength have been recently suggested to be equally or more efficacious and efficient.[1] One such method is the isometric mid-thigh pull (IMTP), which has significant advantages over 1-RM testing, with regard to the time spent testing, volume load considerations, as well as the ability to assess other important strength qualities besides maximal strength (e.g. rate of force development).[2]

In the initial use of the IMTP, the body position selected was chosen to mimic that of the second pull of the clean,[2] the phase in which the highest forces and velocities are generated.[3] However, there are inconsistencies in the methods used for performing the IMTP, namely the precise posture and body position used. Many studies use a knee angle of approximately 120-135,[4-9] but there is variability in what hip angle is used in the studies that report it and several studies do not report hip angle.[10-12] A study by Comfort et al.[13] evaluated changes in force production ability between 9 different body positions, but found that there were no differences between each. However, the findings of the Comfort et al.[13] study ran contrary to findings of another study that evaluated powerlifters.[5]

The purpose of the present study was to evaluate the force production differences that may result from the use of two separate commonly used body positions for execution of the mid-thigh pull. A secondary aim of the study was to evaluate the effects of participants' experience with weightlifting movements on the force produced in each pulling position.

Methods

The present study was a two-part study. For the first part, the differences between an upright and bent body position in the IMTP were evaluated. The second part of the study was performed using exact methods outlined by Comfort et al.[13] in order to compare these methods using the same knee and joint angles used in study 1.

Study 1: Experimental Approach to the Problem

Participants came into the laboratory on 5 separate occasions, separated by 72-96 hours. All participants were free from musculoskeletal injury for at least 6 months. In the first testing session, bar heights and foot position were determined and recorded so that they could be replicated in each subsequent testing session, Participants were then familiarized with the IMTP. At each familiarization session, participants were required to use the same basic pulling procedures in order to standardize testing. In all sessions, the pull position order was randomized to remove testing order bias. Data collected on the fifth and final session were then used to all analyses in the present study.

Study 1: Participants

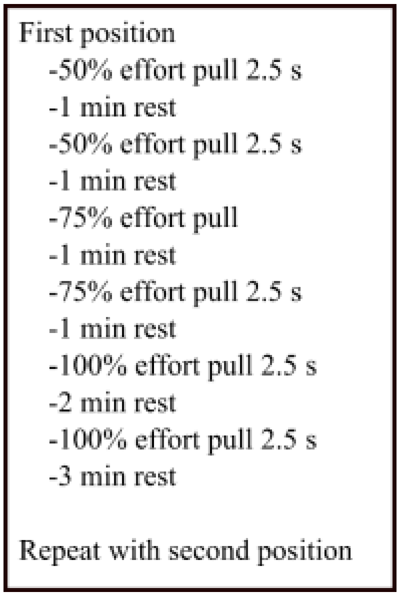
Two groups of participants were recruited for this study. All participants, regardless of group were required to be male and involved in regular physical activity. One group had greater than 6 months of experience training with weightlifting variants. This group was designated the "experience with weightlifting" group (n=12, body weight: 84.4±7.4kg, years of weightlifting: 4.9±4.2y range: 1.07-13.5y). The other group, with less than 6 months experience training with weightlifting variants, was designated the "low experience with weightlifting" group (n=10, body weight: 75.1±11.5kg, years of weightlifting: 0.09±0.09y range: 0-0.24y). Prior to participation, all participants were thoroughly informed of study procedures. Each participant then read and signed informed consent documents according to procedures outlined by the University Institutional Review Board.

Study 1: Isometric Mid-Thigh Pulls

All participants performed the IMTP in a custom power rack (Sorinex, Irmo, SC) that allows the bar to be fixed at any height, while standing on two adjacent force plates (45.5 cm x 91 cm, RoughDeck HP; Rice Lake Weighing Systems). Participants were secured to the bar using lifting straps and athletic tape in accordance with previous methods.[2]

Two separate pulling positions were evaluated during the IMTP. Specifically, a body position which allowed a knee angle of 125° and hip angle of 145° was designated the "upright" position, and a body position which allowed a knee angle of 125° and hip angle of 125° was designated the "bent" position. The knee angle of 125° represents the angle most commonly used in IMTP studies (cite). The two hip angles are meant to approximate the upright body position used in many studies,[7-9] while the bent position mean to approximate the body position used in.[10,13] The bar heights to allow for each body position were determined in the first testing session by using a digital camera (HD Pro Webcam C920, Logitech Inc.) and freely available angle measurement software (Screen Scales, Talon Designs LLP). Participants were instructed to pull on the bar with 50% effort to remove as much slack from the body as possible while joint angles for determining of bar height.

On each testing pulling day, participants performed a standardized warmup of 2 minutes of cycling at 50 watts with 50 to 60 RPM. Participants then performed 6 repetitions each of: forward walking lunges, reverse walking lunges, side lunges, straight leg march, and quadriceps pulls, then 5 bodyweight squats and 5 ballistic bodyweight squats. This standard warmup was specifically chosen to reduce the possibility that the warmup would preferentially benefit either pulling position. After the warmup, the order, intensity and rest of IMTPs went according to procedures outlined in Figure 4.1.



First position
- -50% effort pull 2.5 s
- -1 min rest
- -50% effort pull 2.5 s
- -1 min rest
- -75% effort pull
- -1 min rest
- -75% effort pull 2.5 s
- -1 min rest
- -100% effort pull 2.5 s
- -2 min rest
- -100% effort pull 2.5 s
- -3 min rest

Repeat with second position

Figure 4.1: Testing Progression

To ensure there was minimal slack in the body before initiation of the pull, participants were instructed to use a very small amount of pre-tension.[8] Once in position (verified by viewing the athlete and stability of the force trace), participants received a countdown to begin the pull, then were instructed when to stop in accordance with previous methods.[2] For all maximum effort pulls, participants received substantial encouragement by the investigators to ensure a maximal effort. Before each pull, participants were instructed to “pull as fast and hard as possible” to maximize rate of force development.[14]

On sessions 1, 3, and 4 (familiarization sessions), participants only performed two 100% effort pulls, while on sessions 2 and 5 (testing sessions), participants performed between 2 and 4 pulls. Ideally, participants needed only to perform 2 pulls on sessions 2 and 5, but maximum effort attempts were repeated if errors in pulling were observed (countermovement or a substantial change in body position) or if a ≥250N difference in peak force were measured.[2,7] If 4 trials were needed, the best 2 trials were used for analysis. Only the data from testing session 5 was used for the present study.

Analog data from the force plate were amplified and low-pass filtered at 16 Hz (Transducer Techniques, Temecula, CA), and sampled at 1000 Hz (DAQCard-6063E, National Instruments). Force-time traces were digitally filtered using a 2nd order Butterworth low-pass filter at 10 Hz and analyzed using a custom Labview program (Labview 2010, National Instruments).

Sagittal plane video was recorded for each pull (HD Pro Webcam C920, Logitech Inc.). Joint angles for the knee and hip were evaluated at the start (just before initiation of the pull), and most extreme (point at which joint angles were at their maximum during the pull)

Study 1: Analysis

The following variables were calculated from the force time curve generated during each pull peak force (PF), force at 50ms (F50), force at 90ms (F90), force at 250ms (F250), impulse 0-50ms (IMP50), impulse 0-90ms (IMP90), and impulse (IMP250). In addition, peak force was scaled allometrically to account for bodymass, using the equation $(\text{force}\cdot\text{bodymass}^{-0.67).}$ Prior to statistical analysis, data were screened for within session test-retest reliability, outliers and normality. Reliability was assessed using ICCs with 95% CI, a paired t-test, and CV (typical error of log-transformed data). Each reliability metric was calculated on the entire group, as well as each subset of data (group and position). Data were also screened for violations of assumptions for a mixed-design ANOVA.[15]

Multiple 2x2 mixed ANOVAs (group X pulling position) were run to determine differences between groups and position for each variable tested. Generalized eta-squared (η_g^2) was used for effect sizes and interpreted with the following scale: 0.02 small, 0.13 medium, and

0.26 large.[16,17] In lieu of *post hoc* tests, due to concerns about overall experiment-wise error rate in Study 1, Cohen's d effect size statistics were calculated between pulling positions for the experienced and inexperienced groups. The magnitude of effect sizes was interpreted according to a scale by Hopkins[18] as follows: 0 trivial, 0.2 small, 0.6 moderate, 1.2 large, and >2.0 very large. All analysis was performed in R, using the 'psych', 'effsize', 'pastecs' and 'ezANOVA' analysis packages.[19]

Table 4.1: Reliability results for all subsets of analysis, represented as minimums and maximums for each statistic

	ICC		ICC 95% CI		t-test P Value		CV	
	Min	Max	Min	Max	Min	Max	Min	Max
PF	0.96	0.99	0.85-0.99	0.98-1.00	0.08	0.94	1.9%	5.4%
F50	0.80	0.95	0.00-0.91	0.70-0.98	0.39	0.80	6.8%	9.2%
F90	0.71	0.98	0.57-0.97	0.96-0.99	0.42	0.94	5.6%	11.4%
F250	0.95	0.98	0.79-0.99	0.97-0.99	0.15	0.90	3.3%	5.0%
IMP50	0.89	0.97	0.64-0.97	0.94-0.98	0.21	0.71	6.2%	7.1%
IMP90	0.83	0.97	0.41-0.95	0.93-0.98	0.46	0.99	6.1%	8.0%
IMP250	0.95	0.98	0.72-0.98	0.97-0.99	0.37	0.86	4.6%	6.7%

*negative lower-limit values for 95% CI were truncated to zero. Minimum values are the subset with the lowest value, while maximum is the subset with the highest value observed.

Study 1: Results

The following variables were deemed adequately reliable for analysis: PF, F50, F90, F250, IMP50, IMP90, and IMP250. Reliability statistics can be found in Table 4.1. Descriptive statistics for IMTP variables can be found in Table 4.2.

The results from repeated measures ANOVAs can be found in Table 4.3. All main and interaction effects were statistically significant at the p=0.05 level for each variable tested. Cohen's d between pulling positions for PF, PFa, PF50, PF90, PF250, IMP50, IMP90, and IMP250 in the experienced group were 1.13, 1.15, 0.6, 0.83, 1.2, 0.5, 0.64, 0.94, respectively, and for the inexperienced group, were 0.6, 0.86, 0.34, 0.43, 0.53, 0.2, 0.31, 0.48, respectively. Sagittal plane angle data for the hip and knee are reported in Table 4.4.

Table 4.2: Results from IMTPs

		PF	PFa	F50	F90	F250	IMP50	IMP90	IMP250
Bent	Exp	3660.7	190.8	1724.5	2058.2	2722.3	80.8	156.6	558.2
		±612.4	±31.4	±242.5	±323.5	±425.1	±11.5	±22.1	±86.6
	Inexp	3108.3	174.2	1330.8	1592.1	2213.8	61.7	120.2	435.3
		±677.8	±29.0	±251.8	±351	±349.9	±12	±23.2	±76.3
Upright	Exp	4587.1	238.9	1920.3	2441.2	3421.7	88.5	175.9	669.9
		±981.8	±49.9	±395.5	±562	±688.6	±18.5	±36.4	±144.5
	Inexp	3493.9	196.5	1424.3	1755.5	2401.3	64.1	127.9	474.4
		±568.2	±22.8	±295.1	±399.2	±349.1	±13.6	±26.4	±84.5

Table 4.3: Results of Repeated Measures ANOVAs

	Main Effects		Interaction
Variable	Group	Pull Position	Group by Pull Position
Peak Force	F(1,20)=14.9, *p*=0.012, η_g^2=0.25	F(1,20)=45.7, p<0.001, η_g^2=0.14	F(1,20)=7.8, p=0.01, η_g^2=0.03
Peak Force (allometrically scaled)	F(1,20)=4.3, p=0.052, η_g^2=0.15	F(1,20)=45.8, p<0.001, η_g^2=0.18	F(1,20)=6.2, p=0.022, η_g^2=0.029
Force at 50ms	F(1,20)=12.7, p=0.002, η_g^2=0.37	F(1,20)=14.2, p=0.001, η_g^2=0.04	F(1,20)=4.5, p=0.20, η_g^2=0.00
Force at 90ms	F(1,20)=11.5, p=0.002, η_g^2=0.33	F(1,20)=18.5, p=0.003, η_g^2=0.07	F(1,20)=3.0, p=0.10, η_g^2=0.01
Force at 250ms	F(1,20)=14.8, p=0.001, η_g^2=0.39	F(1,20)=55.5, p<0.001, η_g^2=0.12	F(1,20)=18.5, p<0.001, η_g^2=0.04
Impulse 0-50ms	F(1,20)=13.9, p=0.001, η_g^2=0.39	F(1,20)=7.8, p=0.01, η_g^2=0.02	F(1,20)=2.0, p=0.17, η_g^2=0.01
Impulse 0-90ms	F(1,20)=13.6, p=0.001, η_g^2=0.38	F(1,20)=15.2, p<0.001, η_g^2=0.04	F(1,20)=2.8, p=0.11, η_g^2=0.01
Impulse 0-250ms	F(1,20)=14.1, p=0.001, η_g^2=0.38	F(1,20)=32.9, p<0.001, η_g^2=0.08	F(1,20)=7.6, p=0.01, η_g^2=0.02

Table 4.4: Angle data measured for IMTPs in each position

	Knee			Hip		
	Start (°)	Maximum(°)	Change(°)	Start (°)	Maximum(°)	Change(°)
Bent	122.5±7.3	127.3±5.3	5.0±3.3	120.3±6.9	128.7±6.5	7.4±3.8
Upright	120.9±5.2	127.8±5.2	7.0±3.4	138.1±8.9	148.5±6.8	10.4±6.4

Study 2: Methods

Isometric Mid-Thigh Pulls

A follow up study was performed upon observing different findings from than the study by Comfort et al.[13] on the impact of knee and hip angle on IMTP force-time curve results. Statistically significant differences between positions for all variables tested were observed in study 1, but differences were not found in the study by Comfort et al.[13] To evaluate if differences in results between each of the two studies were due to differences in bar positioning on the thigh (despite similar knee and hip angles used in each study), the following changes to testing procedures were introduced based on methods described in Comfort et al.[13] and correspondence with the authors:

1. A horizontal line was drawn in marker across the thighs marking exactly half the distance between the anterior superior iliac spine and center of the patella. When setting up the participant within the custom power rack, the bar covered the line drawn on the thigh.
2. Foot movement was not allowed to deviate between the two body positions.

Participants for Study 2 were experienced with both weightlifting and the IMTP, albeit with the position described as “upright” (125° knee, 145° hip) in study 1. A total of 8 participants were initially recruited for testing, however two participants were unable to achieve positions outlined above while still able to cover the thigh mark. Another participant increased his hip angle to 140° during the bent pull, and was therefore excluded on the basis that this did not represent the bent position. Furthermore, another participant's video file was corrupted, and not reported in Table 6, but was included in force analysis. All participants recruited for the study were experienced with both weightlifting (>6 months experience) and the IMTP.

All IMTPs were performed in a single session, with the pull position in randomized order. Participants entered the lab, and had their body weight, height, training history taken. Their thighs were marked as outlined above, then entered the rack to measure bar heights for each position. Bar heights and joint angles were determined similarly to study 1. Warmups, rest periods and maximal effort pulls were structured identically to session 5, as used in study 1.

Study 2: Analysis

The Wilcoxon signed rank test was used to compare force-time variables between bent and upright positions due to the small sample size, using a one-tailed hypothesis, as we hypothesized that force variables measured from the upright position would be greater than that of the bent position.

Study 2: Results

Results for the pair-wise comparisons were as follows: peak force p=0.015, force at 50ms p=0.11, force at 90ms p= 0.08, force at 250ms p= 0.02, impulse 0-50ms p=0.08, impulse 0-90ms p=0.08, impulse 0-250ms p=0.02.

Table 4.5: Comparison of between variables for each position for each participant

		Participant				
		1	2	3	4	5
PF	Bent	3171	4491	2410	3738	5056
	Upright	3940	4992	3068	4018	6084
	% Difference	-21.6%	-10.6%	-24.0%	-7.2%	-18.5%
F50	Bent	1866	2579	1099	1522	1943
	Upright	1830	2527	1227	1692	2233
	% Difference	2.0%	2.0%	-11.0%	-10.6%	-13.9%
F90	Bent	2261	3387	1384	1954	2217
	Upright	2275	3308	1729	2124	2951
	% Difference	-0.6%	2.3%	-22.2%	-8.4%	-28.4%
F250	Bent	2734	4036	2035	2824	3529
	Upright	3222	4831	2480	3019	4328
	% Difference	-16.4%	-17.9%	-19.7%	-6.7%	-20.3%
IMP50	Bent	85	116	51	70	92
	Upright	85	121	52	77	98
	% Difference	-0.1%	-4.3%	-2.0%	-9.5%	-6.4%
IMP90	Bent	168	236	100	139	176
	Upright	167	235	112	153	202
	% Difference	0.4%	0.2%	-10.7%	-9.6%	-14.0%
IMP250	Bent	579	854	388	535	658
	Upright	617	934	472	578	831
	% Difference	-6.4%	-9.0%	-19.4%	-7.8%	-23.1%

PF: peak force, F50: force at 50ms, F90: force at 90ms, F250: force at 250ms, IMP50: impulse 0-50ms, IMP90: impulse 0-90ms, IMP250: impulse 0-250ms.

Discussion

The main findings of this two-part study are that there are differences in the force production capabilities for participants performing the IMTP in different body positions. More specifically, the upright position appears to be the superior position in which athletes are able to create higher forces more quickly than in the bent position. The magnitude of force production difference between the bent and upright positions does depend on whether athletes are experienced with weightlifting or not, as indicated by the statistically significant interaction effect. Athletes who are experienced with weightlifting exhibit greater differences between the two positions, as indicated by the moderate to large effect sizes observed (d = 0.5-1.2). Athletes without weightlifting experience still exhibited differences in force generation capacity between the two positions as indicated by the small to moderate effect sizes (d = 0.2-0.6) between positions.

Table 4.6: Individual data from each participant

		Knee			Hip		
	Participant	Start (°)	Max (°)	Change (°)	Start (°)	Max (°)	Change (°)
Bent	1	111.5	121.0	9.5	117.0	122.0	5.0
	2	125.0	131.0	6.0	126.0	130.0	4.0
	3	127.0	127.0	0.0	117.5	123.0	5.5
	4	118.0	122.0	4.0	124.0	135.0	11.0
Upright	1	115.0	126.0	11.0	133.0	139.0	6.0
	2	122.5	131.0	8.5	143.0	147.0	4.0
	3	123.5	126.0	2.5	137.5	147.0	9.5
	4	117.5	128.5	11.0	142.5	154.0	11.5

*Angle data missing for participant 5 due to corrupted video file

From a specificity perspective, it is understandable that the weightlifting-experienced group would exhibit a larger drop off in performance from the upright position. The phase of the clean and snatch with the highest forces is the second pull,[20] which is identical to the upright position used in the present study and previously published research.[6] Since weightlifters frequently train with exercises that require mastery of this position it is possible that they have maximized their ability to develop forces in this position. It is not unexpected that the bent over position results in reduced force production as it corresponds to the beginning of the transition phase which links the first and second pull in weightlifting movements. Overall, the transition phase of the pulling motion always exhibits the lowest forces as a result of the mechanical disadvantages associated with the position in weightlifting.[20] Conceptually, the transition phase functions to reposition the body and prepare the athlete for execution of the second pull where the weightlifter is able to maximize force generation.[21] The increased ability to apply force may be due to better mechanical advantage, muscle lengths, and potentially engagement of the stretch-shortening cycle, although only the former two factors would be afforded to force production in the IMTP, given its isometric execution.

For athletes with less weightlifting experience, it would make sense that there is a reduced difference between the tested positions. These athletes would have spent less time overloading the second pull, and would not be expected to display the effects of training this position. There is however, still an apparent mechanical advantage for using the upright position with athletes who are less experienced with weightlifting movements. Despite the training difference between the two groups, there were still moderate effect sizes between positions. Similarly, a previously published study evaluated the differences in IMTP and a bent-over deadlift-style “lockout” technique on force production capacity with powerlifters.[6] Despite the powerlifters’ lack of experience performing weightlifting movements and their variants, such as the mid-thigh pull position, and the large training volumes the lifters had spent practicing deadlift/overloading the lockout positions, there was still a statistically significant difference ($p<0.001$) in peak force production between the positions and a large effect size ($d = 1.23$).

While the positions used in part 1 of the present study closely mimicked some of the positions used in a study by Comfort et al.,[13] force-production differences were observed between the bent and upright positions. We attempted to replicate exactly the methods used by Comfort et al.[13] in Study 2, in order to address the possibility that the method of positioning in part 1 could account for the observed differences. Despite the changes in part 2, and having similar training backgrounds to those of Comfort et al.,[13] force production differences remained for the later time points (F250, IMP250, PF) for all participants. For early time points (F50, F90, IMP50, IMP90), there were not statistically significant differences, although for 3 of 5 participants the upright position had substantially greater force and impulse values, while the other two participants there were only small differences.

While it is difficult to speculate why no statistical differences in force production between body positions were found in the study by Comfort et al.,[13] some possibilities exist. For example, in all of our participants during the bent position pulls, we observed (from direct observation and video) that nearly all participants attempted to adjust body position into one resembling the upright position. The increase in joint angles during the pull confirms this observation. In addition, in part 2 of the present study, one of our participants was unable to maintain the bent position, and immediately shifted during the pull to one that closely resembled the upright position, and was thus excluded from the study. Two more participants were unable to achieve the correct bent position as specified in the Comfort et al.[13] study, without bending their arms or elevating their shoulder girdle. Had these participants pulled in the bent position, it seems likely they would have increase their hip angle substantially as their elbows extended and shoulder girdle depressed, ending in a body position similar to that of the other excluded participant. While we are unable to verify if the same body movement issues occurred in the Comfort et al.[13] study, it is at least plausible that some amount of angle change occurred, allowing for the force production between positions to be similar.

One particularly interesting finding in the present study is that there is a surprising amount of extension that occurs at the knee and the hip during the execution of the IMTP (observed with video). While every attempt was made to have the participants position themselves while using pre-tension to minimize slack in the body, the high forces produced during the pull exceed those of pre-tension used to determine position by a large margin. It was also apparent that the “pretension” that participants applied to the bar when setting up their body positions was inconsistent. We used consistent bar heights and foot placement, yet not every participant consistently achieved the precise starting position even after copious amounts of familiarization. Participants did however achieve the desired body position at some point during the pull, whether it was at the starting, during the pull, or at the peak extended position.

Some recent research has begun using a “self-selected” position when executing the IMTP.[22-24] One potential issue with using a non-standardized position is that different participants may performing better or worse than would be possible using a standardized optimal (from a force production perspective) position. Our studies indicate that positioning does matter, and that force differences exist between positions. Should the “self-selected” position used by any given individual vary between individuals, it may result in latent variability in performance whose presence and magnitude is unknown to the researchers. This adds a potentially large source of error into values obtained from the IMTP. In addition, given that the difference in performance between positions depended on level of experience with weightlifting in the present study, we can conclude that the problem of error may be further exacerbated by the training background of participants.

Practical Applications

In future studies or in practice, we recommend the isometric mid-thigh pull be performed with a 120-135 knee angle, and approximately a 140-150 hip angle (upright torso). Bar heights and body positions should be verified under tension, and researchers should expect joint angles to increase to some degree during the pull. Consistent bar heights and joint angles should be used when testing over time to ensure that the effect of body position is accounted for.

Conclusions

The findings of this study indicate that the posture in which the isometric mid-thigh pull is executed matters to force production, regardless of experience with weightlifting variations. Furthermore, studies should report both the knee and hip angles used for their athletes for greater ease in comparing results between studies.

References

1. McMaster DT, Gill N, Cronin J, McGuigan M. A brief review of strength and ballistic assessment methodologies in sport. *Sports Med.* 2014;44(5):603-623.
2. Haff GG, Stone M, O'Bryant HS, et al. Force-Time Dependent Characteristics of Dynamic and Isometric Muscle Actions. *J. Strength Cond. Res.* 1997;11(4):269-272.
3. Kauhanen H, Häkkinen K, Komi PV. A biomechanical analysis of the snatch and clean & jerk techniques of Finnish elite and district level weightlifters. *Scand J Sports Sci.* 1984;6(2):47-56.
4. Hornsby WG, Haff GG, Sands WA, et al. Alterations in strength characteristics for isometric and dynamic mid-thigh pulls in collegiate throwers across 11 weeks of training. *Gazz. Med. Ital.* 2013;172(12):929-940.
5. Beckham GK, Lamont HS, Sato K, Ramsey MW, Haff GG, Stone MH. Isometric Strength of Powerlifters in Key Positions of the Conventional Deadlift. *J. Trainology.* 2012;1(2):32-35.
6. Haff GG, Carlock JM, Hartman MJ, et al. Force-time curve characteristics of dynamic and isometric muscle actions of elite women olympic weightlifters. *J. Strength Cond. Res.* 2005;19(4):741-748.
7. Kraska JM, Ramsey MW, Haff GG, et al. Relationship between strength characteristics and unweighted and weighted vertical jump height. *Int. J. Sports Physiol. Perform.* 2009;4(4):461-473.
8. Beckham G, Mizuguchi S, Carter C, et al. Relationships of isometric mid-thigh pull variables to weightlifting performance. *J. Sports Med. Phys. Fitness.* 2013;53(5):573-581.

9. Stone MH, Sands WA, Pierce KC, Carlock J, Cardinale M, Newton RU. Relationship of maximum strength to weightlifting performance. *Med. Sci. Sports Exerc.* 2005;37(6):1037-1043.

10. McGuigan MR, Newton MJ, Winchester JB. Use of isometric testing in soccer players. *J Aus Strength Cond Assn.* 2008;16(4):11-14.

11. McGuigan MR, Winchester JB. The relationship between isometric and dynamic strength in college football players. *J Sport Sci & Med.* 2008;7(1):101-105.

12. McGuigan MR, Winchester JB, Erickson T. The importance of isometric maximum strength in college wrestlers. *J. Sports Sci. Med.* 2006;5(CSSI):108-113.

13. Comfort P, Jones PA, McMahon JJ, Newton R. Effect of knee and trunk angle on kinetic variables during the isometric midthigh pull: test-retest reliability. *Int. J. Sports Physiol. Perform.* 2015;10(1):58-63.

14. Bemben MG, Clasey JL, Massey BH. The effect of the rate of muscle contraction on the force-time curve parameters of male and female subjects. *Res. Q. Exerc. Sport.* 1990;61(1):96-99.

15. Tabachnick B, Fidell L. *Experimental Design Using Anova.* Belmont, CA: Duxbury/Thomson; 2007.

16. Cohen J. *Statistical Power Analysis for the Behavioral Sciences.* 2nd ed. New Jersey: Lawrence Erlbaum Association; 1988.

17. Bakeman R. Recommended effect size statistics for repeated measures designs. *Behav. Res. Methods.* 2005;37(3):379-384.

18. Hopkins WG. A scale of magnitude for effect statistics. 2014. http://sportsci.org/resource/stats/effectmag.html.

19. R Core Team. R: A Language and Environment for Statistical Computing. Vienna, Austria2014.

20. Häkkinen K, Kauhanen H, Komi PV. Biomechanical changes in the olympic weightlifting technique of the snatch and clean & jerk from submaximal to maximal loads. *Scand J Sports Sci.* 1984;6(2):57-66.

21. Enoka RM. The pull in olympic weightlifting. *Med. Sci. Sports.* 1979;11(2):131-137.

22. Thomas C, Jones PA, Comfort P. Reliability of the Dynamic Strength Index in Collegiate Athletes. *Int. J. Sports Physiol. Perform.* 2014.

23. Thomas C, Comfort P, Chiang C-y, Jones PA. Relationship between isometric mid-thigh pull variables and sprint and change of direction performance in collegiate athletes. *J. Trainology*. 2015;4:6-10.

24. Thomas C, Jones PA, Rothwell J, Chiang CY, Comfort P. An Investigation into the Relationship between Maximum Isometric Strength and Vertical Jump Performance. *J. Strength Cond. Res.* 2015.

CHAPTER 5

EFFECT OF BODY POSITION ON MUSCLE ACTIVATION DURING THE ISOMETRIC MID-THIGH PULL

Abstract

Both upright and bent body positions have been used for the isometric mid-thigh pull (IMTP) in the literature. Based upon the contemporary body of scientific knowledge there are conflicting results regarding the impact of body position on the ground reaction forces generated during the isometric mid-thigh pull. It is possible that body position used in the IMTP may play a role in muscle activation during execution of the test, and thus the performance therein. This study evaluated average root-mean-square muscle activation between upright and bent body positions in the IMTP for various lower body muscular with surface EMG. The bent position resulted in greater lumbar erector spinae activation and biceps femoris activation, while the upright position had greater upper trapezius and vastus medialis activation. These differences in activation are probably the result of different moment arm lengths and different orientations of limbs and joints relative to both the line of pull on the bar and gravity. The results of the present study suggest that the body position utilized during the isometric mid-thigh pull directly impacts muscle activation patterns. Alterations in body position may directly impact the transferability of test results to sport specific performances as a result of altering muscle activation patterns. Additionally the bent over position significantly increase the activation of lower back musculature and may put the athlete at risk for lower back injuries.

Keywords: kinetics, lower back injury, maximal strength

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Introduction

Among many other worthwhile methods to evaluate the performance abilities of athletes, maximal strength testing has proven to be useful in providing insight into both underlying characteristics related to other areas of performance and the progress of an athlete throughout a periodized training program.[1] One such method of evaluating maximal strength is the isometric mid-thigh pull (IMTP), which has shown its usefulness not only as a strength test,[2] but as a means to evaluate rate of force development[3,4] and potential performance on other tests.[5]

Recently, there has been debate over the ideal body position to use for the IMTP.[4,6] While many studies have used an upright body position similar to that of the second pull of the clean as originally suggested,[2] some studies have used a bent-over body position.[7] To the authors' knowledge, the only two studies to date that directly evaluated the impact of body position during the isometric mid-thigh pull on force time-curve characteristics. Interestingly, these two studies had divergent conclusions regarding the impact of body position. Specifically, Beckham, et al.[6] reported a difference in peak ground reaction force production between an upright IMTP and a "lockout" position during a simulated deadlift, while Comfort, et al.[4] reported no force production differences between a range of knee and hip angles. Neither study considered the effects of body position on muscle activation, which may help to elucidate the presence of quantitative or qualitative differences between positions used in the IMTP. It is thus it is the purpose of this study to evaluate the muscle activation differences between upright and bent body positions in the IMTP.

Methods

Experimental Approach

This study evaluated the effect of using a bent or upright body position for the IMTP on activation of torso and lower-body musculature. Participants had substantial prior familiarization with the IMTP (5 sessions, separate by 72-96 hours), and performed both positions in randomized order.

Participants

Participants for the study were recreationally active with less than 6 months of weightlifting experience (n=10, body weight: 75.1±11.5kg, years of weightlifting: 0.09±0.09y range: 0-0.24y), or resistance-trained with greater than 6 months of weightlifting experience (n=12, body weight: 84.4±7.4kg, years of weightlifting: 4.9±4.2y range: 1.07-13.5y). All subjects had been free of injury for at least 6 months prior to participation in the study. Subjects had previously read and signed informed consent documents in accordance with the University Institutional Review Board.

Isometric Mid-Thigh Pulls

Participants performed the IMTP standing on two adjacent force plates (45.5 cm x 91 cm, RoughDeck HP; Rice Lake Weighing Systems) in a custom power-rack that allows for fixation of the bar in any height. Participants used lifting straps and were taped with athletic tape to remove grip as a limiting factor in pull performance, in accordance with previous methods [2]. In order to assess the impact of body position during the IMTP, two positions were selected for performing the IMTP, based on the work of prior studies.[2,4] A “bent” position was used, with a 145° hip angle and 125° knee angle. An “upright” position was also used, with a 125° hip angle and 125° knee angle. Bar heights used for IMTPs were determined in the first familiarization session by using sagittal plane video (HD Pro Webcam C920, Logitech, Inc.) and freely available measurement software to measure knee and hip angles (Screen Scales, Talon Designs LLP). During measurement of initial bar position, participants pulled on the bar with moderate effort in an attempt to minimize slack in the body.[8]

Prior to performing the IMTP, participants cycled for 2 minutes at 50 watts and 50-60 RPM then performed 6 repetitions each of: forward and backward walking lunges, side lunges, straight leg march, quadriceps pulls, then performed 5 bodyweight squats, and 5 ballistic bodyweight squats. While this warmup contrasts those used in other IMTP studies, this warmup was specifically chosen to avoid preferencing performance in either the upright or the bent position. After the standardized warmup, in randomized order, participants performed in either the bent or upright position. Participants performed two 50% warmup trials, separated by one minute, and two 75% effort warmup trials, separated by one minute, then performed the first 100% trial after one minute of rest. Between two and four 100% trials were then completed, with each trial separated by two minutes each. Additional 100% trials were only completed if visible errors in technique were exhibited (countermovement, excessive backward lean), or if greater than 250N were observed between trials.[5]

EMG Data

The EMG activity of the following muscles on the right side of the body were measured for this study: biceps femoris, vastus medialis, vastus lateralis, gluteus maximus, lumbar erector spinae, lower trapezius, and upper trapezius. The precise location of surface electrode sites were determined using recommendations by SENIAM[9] and modified slightly when necessary to accommodate varying body dimensions and muscle architecture. Sites for electrodes were prepared by shaving body hair, gently abrading the skin, and cleansing with 70% isopropyl alcohol. Pre-gelled bipolar Ag/AgCL electrodes (2cm inter-electrode distance, center to center) were placed after sufficient time for the isopropyl alcohol to evaporate. Adequate placement and preparation procedures were verified using manual muscle tests for each muscle in the protocol.

EMG data were collected using an 8 channel Noraxon TeleMyo 2400GT (Noraxon USA, Inc.). Important specifications of collection were as follows: differential input impedance of 10MΩ, gain of 1000, common-mode rejection ratio of >100 dB at 60Hz. Data were band-pass filtered between 10 and 600Hz. Data were band-pass filtered between 20 Hz and 500Hz and converted to a linear envelope using the Root Mean Square method with 50ms window.[10] Data over the entire duration of the pull was averaged; this mean value was used for later analysis.

Generally, EMG data are normalized in some manner.[11] One of the most common normalization methods is to divide a calculated EMG value by a maximum value obtained in a maximum voluntary contraction (MVC). However, in this study, because the IMTP is, in essence, a MVC, normalization procedures were not used. Comparison between individual muscles and between groups was not done given the lack of normalization. Comparison between muscles is not recommended due to sources of error and variability in EMG signal specific to a given muscle and electrode placement.[12]

Analysis

The test-retest reliability of measurements was assessed using intraclass correlations (ICCs) and the typical error of natural log-transformed values (CV). Muscle activation was compared between positions for both subgroups separately. P-values from both groups of t-tests were adjusted using the Holms Sequential Bonferroni method in order to control for Type-I error rate.[13] Muscle activation between pulling positions was compared for each group separately using Hedges' g. The magnitude of effect sizes were interpreted according to a scale developed by Hopkins[14]; effect sizes between 0.0-0.2, 0.2-0.6, 0.06-1.2, and 1.2-2, and >2.0 were deemed trivial, small, moderate, large, and very large, respectively.

Results

Reliability data are displayed in Table 5.1. Comparisons for muscle activation between upright and bent positions for pooled data are found in Table 5.2. Effect sizes for muscle activation between positions for the two groups are found in Figure 5.1. The experienced group had statistically greater vastus lateralis activation in the upright position. Vastus medialis activation was slightly higher in the upright position and approached statistical significance (p=0.07, g=0.438). The experienced group exhibited greater activation in the bent position for the lumbar erector spinae (p=0.002, g=0.632), and upper trapezius (p=0.014, g=0.385). The inexperienced group exhibited greater activation of the biceps femoris and erector spinae in the bent position (p=0.041, g=0.687; p=0.007, g=0.569, respectively). For the inexperienced group there was slightly higher lower trapezius activation; the comparison approached statistical significance (p=0.054, g=0.415) No other comparisons were statistically significant.

Table 5.1: Reliability Results

Position	Muscle	ICC	ICC 95% CI	CV
Bent	Vastus Medialis	0.98	0.94 - 0.99	9.4%
	Vastus Lateralis	0.98	0.94 - 0.99	12.6%
	Biceps Femoris	0.98	0.95 - 0.99	13.6%
	Gluteus Maximus	0.98	0.94 - 0.99	8.1%
	Lumbar Erector Spinae	0.99	0.97 - 1.00	4.7%
	Lower Trapezius	0.99	0.98 - 1.00	8.1%
	Upper Trapezius	1.00	0.99 - 1.00	4.4%
Upright	Vastus Medialis	0.88	0.71 - 0.95	12.1%
	Vastus Lateralis	0.96	0.90 - 0.98	11.2%
	Biceps Femoris	0.95	0.88 - 0.98	23.0%
	Gluteus Maximus	0.97	0.92 - 0.99	9.8%
	Lumbar Erector Spinae	0.95	0.89 - 0.98	13.6%
	Lower Trapezius	0.97	0.94 - 0.99	14.1%
	Upper Trapezius	0.99	0.98 - 1.00	6.6%

Table 5.2: Comparison of muscle activation between pull positions for each group

	Experienced		Inexperienced	
Muscle	p-value	Hedges' g	p-value	Hedges' g
Vastus Medialis	0.070	-0.438	0.358	-0.522
Vastus Lateralis	0.005*	-0.504	0.674	0.109
Biceps Femoris	0.228	0.188	0.041*	0.687
Gluteus Maximus	0.206	0.273	0.358	0.220
Lumbar Erector Spinae	0.002*	0.632	0.007*	0.569
Lower Trapezius	0.560	0.065	0.054	0.415
Upper Trapezius	0.014*	-0.385	0.090	-0.327

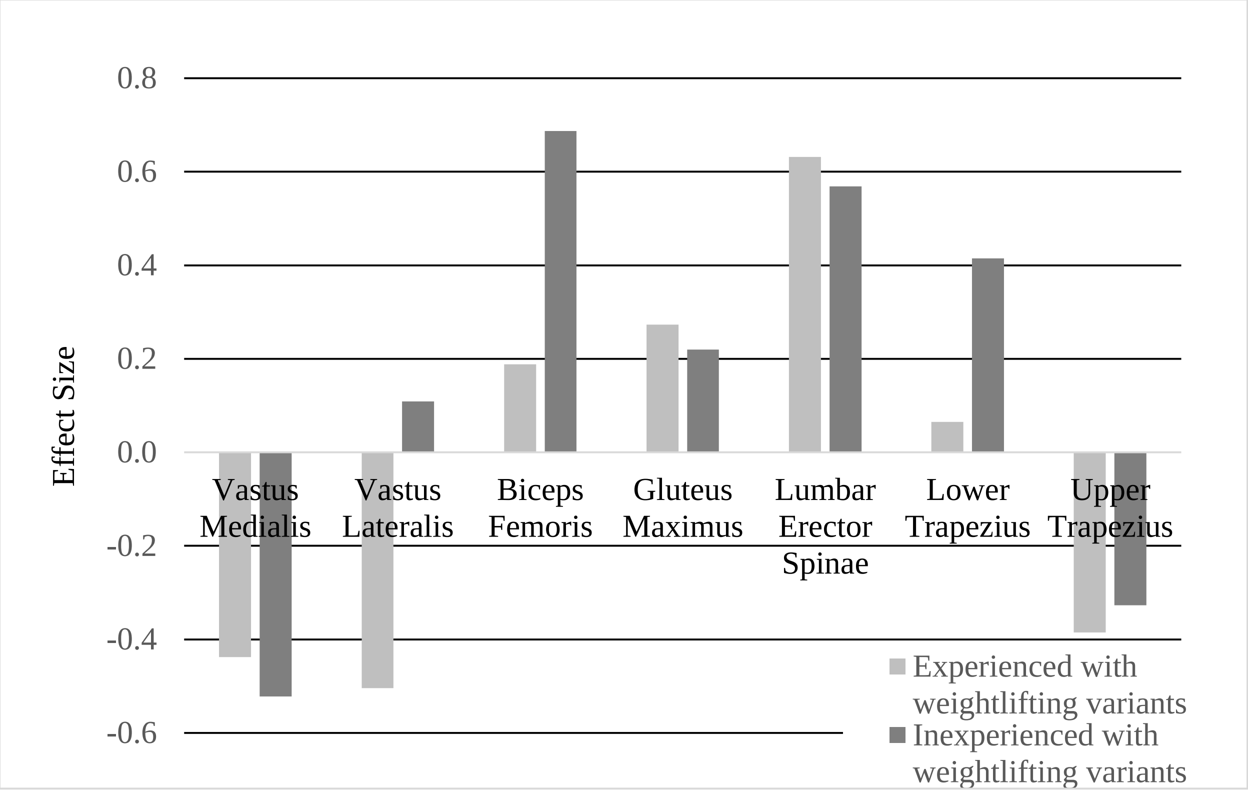

Figure 5.1: Effect sizes for the difference of muscle activation between pull positions for each group.

Negative effect sizes indicate that the upright position had greater values, positive values that the bent position had greater values

Discussion

The main findings of this study are that there are different patterns of activation in the IMTP when using different body positions. Both the groups saw greater erector spinae activation in the bent position. The experienced group favored knee extensor and upper trapezius activation while upright, while the inexperienced group favored biceps femoris activity during the bent position. The differences in lumbar erector spinae activation seen in both groups are likely explainable through changes in the angle of the torso relative to gravity and the position of the bar. Relative to the upright position, the bent position results in a longer lumbar moment arm.[15]

The difference in body positioning, and subsequent change in lumbar moment arms and moments are similar to that observed between the transition phase and the second pull of the clean.[16] In order to stabilize the lumbar spine and generate maximal force, greater activation of spinal extensors is required offset the longer moment arms.

Greater activation in the lumbar extensors may be indicative of greater risk for lower back injury in performing the test with the bent over posture, given that lumbar extensor moments are positively linearly related to lumbar erector spinae activation.[17] The 125° hip angle necessarily requires a torso that is further from the vertical than the upright position. By increasing the torso angle relative to the forces imparted into the bar and the force plates (closer to perpendicular instead of force and torso in parallel), there is less force distributed axially along the spine in compression, and more distributed as shear. The posture used in the bent position likely comes with a greater lumbar moment arm, which is also accompanied by greater shear forces on the lumbar spine and intervertebral discs. In this bent position, stabilizer and extensor muscles of the spine must activate to a greater extent to counteract increased shear forces,[18] indeed, greater erector spinae activation was observed in the bent position. Given that shear forces have been suggested as a risk factor for lower back injury,[19] choosing a body position that results in less non-compressive spinal forces may be prudent for minimizing risk of lower back injury.

Some of the differences observed between position were idiosyncratic to the experience a subject has with weightlifting variations. In particular, the group experienced with weightlifting exhibited greater knee extensor and shoulder girdler elevator activation in the upright position. In the second pull of the clean, a weightlifter must powerfully extend the knees and hips while powerfully elevating the shoulder girdle.[20] It is reasonable to infer that the weightlifting-experienced group, with substantial practice performing a combination of joint actions necessary for an effective second pull, would be able to effectively do so in the upright IMTP. Interestingly, the group inexperienced with weightlifting derivatives had greater biceps femoris activation in the bent position, yet the experienced group did not. The biceps femoris activity itself is likely explained by the greater hip moment and longer moment arm in the bent position. However, why this same finding was not also observed in the experienced group is not clear.

The observed differences in muscle activation between positions may indicate that performance in either of the two positions represents different aspects of performance, and would thus be different in how each relate to other sporting tasks. There is probably some degree of generality of performance between both positions; one would expect high performers in the bent position to perform similarly in the upright position. However, each position may be more or less specific to a given task given the differences in muscle recruitment. A task such as a countermovement jump requires large knee and hip extensor torques.[21] Increasing jump height could potentially come from increased knee extensor forces or decreased coactivation of the hamstring, an antagonist.[21] The upright position elicited greater knee extensor activation in the experienced group, and the bent position elicited greater hamstring activation in the inexperienced group. It may be that the upright position relates better to countermovement jumps in weightlifting-experienced athletes due to the increased activation of muscles that create a torque beneficial to jumping, and relates better to countermovement jumps in weightlifting-inexperienced athletes due to decreased activity of an opposing muscle torque. Further research is needed to address differences in how each body position is able to infer performance in other tests.

Conclusion

There are distinct differences in general muscle activation between the upright and bent isometric mid-thigh pull positions. These differences in muscle activation patterns appear to be related to the body position in which the isometric mid-thigh pull is performed. Alterations in the body position may change the mechanical advantage for a given joint, thus requiring different activation of muscles around each joint to create a given external force. Additionally, the increased lumbar strain associated with the bent position may have implications related to overall lower back injury risk. This contention is supported by the moderate increases in lumbar erector spinae activation associated with the bent position.

REFERENCES

1. McMaster DT, Gill N, Cronin J, McGuigan M. A brief review of strength and ballistic assessment methodologies in sport. *Sports Med.* 2014;44(5):603-623.
2. Haff GG, Stone M, O'Bryant HS, et al. Force-Time Dependent Characteristics of Dynamic and Isometric Muscle Actions. *J. Strength Cond. Res.* 1997;11(4):269-272.
3. Haff GG, Ruben RP, Lider J, Twine C, Cormie P. A comparison of methods for determining the rate of force development during isometric midthigh clean pulls. *J. Strength Cond. Res.* 2015;29(2):386-395.
4. Comfort P, Jones PA, McMahon JJ, Newton R. Effect of knee and trunk angle on kinetic variables during the isometric midthigh pull: test-retest reliability. *Int. J. Sports Physiol. Perform.* 2015;10(1):58-63.
5. Kraska JM, Ramsey MW, Haff GG, et al. Relationship between strength characteristics and unweighted and weighted vertical jump height. *Int. J. Sports Physiol. Perform.* 2009;4(4):461-473.
6. Beckham GK, Lamont HS, Sato K, Ramsey MW, Haff GG, Stone MH. Isometric Strength of Powerlifters in Key Positions of the Conventional Deadlift. *J. Trainology.* 2012;1(2):32-35.
7. McGuigan MR, Newton MJ, Winchester JB. Use of isometric testing in soccer players. *J. Aus. Strength. Cond. Assn.* 2008;16(4):11-14.
8. Beckham G, Mizuguchi S, Carter C, et al. Relationships of isometric mid-thigh pull variables to weightlifting performance. *J. Sports Med. Phys. Fitness.* 2013;53(5):573-581.

9. SENIAM. Recommendations for sensor locations on individual muscles. 2014; www.SENIAM.org.

10. de Luca CJ. *Surface Electromyography: Detection and Recording.* DELSYS;2002.

11. Burden A. How should we normalize electromyograms obtained from healthy participants? What we have learned from over 25 years of research. *J. Electromyogr. Kinesiol.* 2010;20(6):1023-1035.

12. Lehman GJ, McGill SM. The importance of normalization in the interpretation of surface electromyography: a proof of principle. *J. Manipulative Physiol. Ther.* 1999;22(7):444-446.

13. Abdi H. Holm's Sequential Bonferroni Procedure. In: Salkind N, ed. *Encyclopedia of Research Design*. Thousand Oaks, CA: Sage; 2010.

14. Hopkins WG. A scale of magnitude for effect statistics. 2014. http://sportsci.org/resource/stats/effectmag.html.

15. Fry AC, Smith JC, Schilling BK. Effect of knee position on hip and knee torques during the barbell squat. *J. Strength Cond. Res.* 2003;17(4):629-633.

16. Enoka RM. The pull in olympic weightlifting. *Med. Sci. Sports.* 1979;11(2):131-137.

17. Dolan P, Adams MA. The relationship between EMG activity and extensor moment generation in the erector spinae muscles during bending and lifting activities. *J. Biomech.* 1993;26(4-5):513-522.

18. Potvin JR, Norman RW, McGill SM. Reduction in anterior shear forces on the L 4L 5 disc by the lumbar musculature. *Clin. Biomech.* 1991;6(2):88-96.

19. McGill SM, Hughson RL, Parks K. Changes in lumbar lordosis modify the role of the extensor muscles. *Clin. Biomech.* 2000;15(10):777-780.

20. Takano B. Coaching optimal technique in the snatch and the clean and jerk: Part II. *Strength. Cond. J.* 1987;9(6):52-56.

21. Lees A, Vanrenterghem J, De Clercq D. The maximal and submaximal vertical jump: implications for strength and conditioning. *J. Strength. Cond. Res.* 2004;18(4):787-791.

CHAPTER 6

SUMMARY AND FUTURE RESEARCH

The purpose of this dissertation to was to evaluate certain specific aspects of performance of the IMTP. In particular, the first study sought to evaluate the existence of an effect of familiarization on ground reaction force production while considering how the body position used for the IMTP and how subjects' experience with weightlifting variations might affect said familiarization, should it exist. Over five days of testing, it did not appear that there was any evident learning effect for either of the two experience groups or in either body position. The second study evaluated the effect of body position and experience level on force production in the IMTP. There were differences in a variety of force measures between each body position, however the magnitude of the difference in force production between the two positions depended on whether the subject was or was not experienced with weightlifting derivatives. Overall, force production was higher in the upright body position compared to the bent body position, although the difference between the two positions was greater for the group experienced with weightlifting. Finally, in the third study, the effects of body position and experience with weightlifting on average muscle activation of the biceps femoris, vastus medialis, vastus lateralis, gluteus maximus, lumbar erector spinae, lower trapezius, and upper trapezius muscles were evaluated. Both the experienced and inexperienced group had higher muscle activation for the erector spinae while in the bent position. However, the group experienced with weightlifting had higher average activation for the upper trapezius, and vastus lateralis, with vastus medialis approaching statistical significance. The group without weightlifting experience had greater biceps femoris activation for the bent IMTP position.

Practical Applications

The IMTP test has become more popular in recent years, and there is now more evidence to suggest best practices for using this particular measure of strength and rate of force development. In particular, it appears that only some familiarization is necessary to be able to perform the test to the best of one's ability. While some familiarization is likely needed, a very high number of trials is probably unnecessary to get a best effort. While there has been some controversy as to the ideal body position to use when performing the IMTP, it has become clear that an upright body position, with a knee angle of 125°-135° and hip angle of 140°-150° is ideal for maximum force production. Deviation from this body position, especially into a more bent-over posture, is likely to negatively influence the force production a participant is able to exert. Finally, the posture used also has an effect on muscle recruitment during the test. While there are some differences between subjects that do and do not have significant weightlifting experience, the bent position shows clear indication of greater lower back activation, which might be an indication of higher lower back stress. For optimal force production and lower injury risk to the low back, an upright body position is recommended for the IMTP.

Future Research

While the study 1 of this dissertation did not find a familiarization effect, it is possible that there was adequate familiarization even from the first day of the testing protocol. The testing protocol used two trials at 50% effort, two trials at 75%, and two trials at 100% effort on the first testing session. It is possible this is enough familiarization, however previous studies typically use less familiarization trials than were used in this study. Further research might consider evaluating a smaller number of familiarization trials, in order to adequately select an appropriate number of trials such that there is an optimal balance of minimal fatigue and adequate familiarization. Studies 2 and 3, combined with prior studies, made a clear case recommending the use of the upright body position for general use. However, there are specific cases where other postures may be useful with respect to specificity, such as rowers, whose sport requires generation of forces while in a more acute hip angle than that of the upright IMTP. Futures studies should use the upright IMTP to evaluate the test’s ability to provide insight into other potentially useful measures of performance, such asymmetry. Additionally, further research into the predictive use of the IMTP may be warranted to provide insight into other skills that rely on high force and rate of force production from the lower body, such as agility, rebounding, blocking, and other skills.

REFERENCES

Abdi, H. (2010). Holm's Sequential Bonferroni Procedure. In N. Salkind (Ed.), *Encyclopedia of Research Design*. Thousand Oaks, CA: Sage.

Bailey, C., Sato, K., Alexander, R., Chiang, C.-y., & Stone, M. H. (2013). Isometric force production symmetry and jumping performance in collegiate athletes. *Journal of Trainology, 2*, 1-5.

Bakeman, R. (2005). Recommended effect size statistics for repeated measures designs. *Behavior Research Methods, 37*(3), 379-384. doi: 10.3758/BF03192707

Baker, D., Wilson, G., & Carlyon, B. (1994). Generality versus specificity: a comparison of dynamic and isometric measures of strength and speed-strength. *European Journal of Applied Physiology and Occupational Physiology, 68*(4), 350-355.

Beckham, G., Mizuguchi, S., Carter, C., Sato, K., Ramsey, M., Lamont, H., . . . Stone, M. (2013). Relationships of isometric mid-thigh pull variables to weightlifting performance. *Journal of Sports Medicine and Physical Fitness, 53*(5), 573-581.

Beckham, G. K., Lamont, H. S., Sato, K., Ramsey, M. W., Haff, G. G., & Stone, M. H. (2012). Isometric Strength of Powerlifters in Key Positions of the Conventional Deadlift. *Journal of Trainology, 1*(2), 32-35.

Beckham, G. K., Suchomel, T. J., Bailey, C. A., Sole, C. J., & Grazer, J. L. (2014). *The relationship of the reactive strength index-modified and measures of force development in the isometric mid-thigh pull.* Paper presented at the Annual Conference for the International Society for Biomechanics in Sports, Johnson City, TN.

Bemben, M. G., Clasey, J. L., & Massey, B. H. (1990). The effect of the rate of muscle contraction on the force-time curve parameters of male and female subjects. *Research Quarterly for Exercise and Sport, 61*(1), 96-99. doi: 10.1080/02701367.1990.10607484

Bemben, M. G., Massey, B. H., Boileau, R. A., & Misner, J. E. (1992). Reliability of isometric force-time curve parameters for men aged 20-79. *J Appl Sport Sci Res, 6*(3), 158-164.

Benton, M. J., Swan, P. D., & Peterson, M. D. (2009). Evaluation of multiple one repetition maximum strength trials in untrained women. *Journal of Strength and Conditioning Research, 23*(5), 1503-1507. doi: 10.1519/JSC.0b013e3181b338b3

Blazevich, A. J., Gill, N., & Newton, R. U. (2002). Reliability and validity of two isometric squat tests. *Journal of Strength and Conditioning Research, 16*(2), 298-304.

Burden, A. (2010). How should we normalize electromyograms obtained from healthy participants? What we have learned from over 25 years of research. *Journal of Electromyography and Kinesiology, 20*(6), 1023-1035. doi: 10.1016/j.jelekin.2010.07.004

Caldwell, L. S., Chaffin, D. B., Dukes-Dobos, F. N., Kroemer, K. H., Laubach, L. L., Snook, S. H., & Wasserman, D. E. (1974). A proposed standard procedure for static muscle strength testing. *American Industrial Hygiene Association Journal, 35*(4), 201-206. doi: 10.1080/0002889748507023

Chaffin, D. B. (1975). Ergonomics guide for the assessment of human static strength. *American Industrial Hygiene Association Journal, 36*(7), 505-511. doi: 10.1080/0002889758507283

Churchill, E., Churchill, T., McConville, J. T., & White, R. M. (1977). *Anthropometric of women of the U.S. Army 1977*. Natick, MA.

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences* (2nd ed.). New Jersey: Lawrence Erlbaum Association.

Comfort, P., Jones, P. A., McMahon, J. J., & Newton, R. (2015). Effect of knee and trunk angle on kinetic variables during the isometric midthigh pull: test-retest reliability. *International Journal of Sports Physiology and Performance, 10*(1), 58-63. doi: 10.1123/ijspp.2014-0077

Cormie, P., Deane, R. S., Triplett, N. T., & McBride, J. M. (2006). Acute effects of whole-body vibration on muscle activity, strength, and power. *Journal of Strength and Conditioning Research, 20*(2), 257-261. doi: 10.1519/R-17835.1

Cormie, P., McCaulley, G. O., Triplett, N. T., & McBride, J. M. (2007). Optimal loading for maximal power output during lower-body resistance exercises. *Medicine and Science in Sports and Exercise, 39*(2), 340-349. doi: 10.1249/01.mss.0000246993.71599.bf

Cormie, P., McGuigan, M. R., & Newton, R. U. (2011). Developing maximal neuromuscular power: part 2 - training considerations for improving maximal power production. *Sports Medicine, 41*(2), 125-146. doi: 10.2165/11538500-000000000-00000

Crewther, B. T., Kilduff, L. P., Cook, C. J., Cunningham, D. J., Bunce, P. J., Bracken, R. M., & Gaviglio, C. M. (2012). Scaling strength and power for body mass differences in rugby union players. *Journal of Sports Medicine and Physical Fitness, 52*(1), 27-32.

Cronin, J. B., & Henderson, M. E. (2004). Maximal strength and power assessment in novice weight trainers. *Journal of Strength and Conditioning Research, 18*(1), 48-52.

Darrall-Jones, J. D., Jones, B., & Till, K. (2015). Anthropometric and Physical Profiles of English Academy Rugby Union Players. *Journal of Strength and Conditioning Research*, 1-1. doi: 10.1519/JSC.0000000000000872 de Luca, C. J. (2002). Surface Electromyography: Detection and Recording: DELSYS.

Dolan, P., & Adams, M. A. (1993). The relationship between EMG activity and extensor moment generation in the erector spinae muscles during bending and lifting activities. *Journal of Biomechanics, 26*(4-5), 513-522. doi: 10.1016/0021-9290(93)90013-5

Enoka, R. M. (1979). The pull in olympic weightlifting. *Medicine and Science in Sports, 11*(2), 131-137.

Folland, J. P., & Williams, A. G. (2007). The adaptations to strength training : morphological and neurological contributions to increased strength. *Sports Medicine, 37*(2), 145-168.

Fry, A. C., Smith, J. C., & Schilling, B. K. (2003). Effect of knee position on hip and knee torques during the barbell squat. *Journal of Strength and Conditioning Research, 17*(4), 629-633.

Graves, J. E., Pollock, M. L., Jones, A. E., Colvin, A. B., & Leggett, S. H. (1989). Specificity of limited range of motion variable resistance training. *Medicine and Science in Sports and Exercise, 21*(1), 84-89.

Haff, G. G., Carlock, J. M., Hartman, M. J., Kilgore, J. L., Kawamori, N., Jackson, J. R., . . . Stone, M. H. (2005). Force-time curve characteristics of dynamic and isometric muscle actions of elite women olympic weightlifters. *Journal of Strength and Conditioning Research, 19*(4), 741-748.

Haff, G. G., Jackson, J. R., Kawamori, N., Carlock, J. M., Hartman, M. J., Kilgore, J. L., . . . Stone, M. H. (2008). Force-time curve characteristics and hormonal alterations during an eleven-week training period in elite women weightlifters. *Journal of Strength and Conditioning Research, 22*(2), 433-446. doi: 10.1519/JSC.0b013e31816191be

Haff, G. G., Ruben, R. P., Lider, J., Twine, C., & Cormie, P. (2015). A comparison of methods for determining the rate of force development during isometric midthigh clean pulls. *Journal of Strength and Conditioning Research, 29*(2), 386-395. doi: 10.1519/JSC.0000000000000705

Haff, G. G., Stone, M., O'Bryant, H. S., Harman, E., Dinan, C., Johnson, R., & Han, K.-H. (1997). Force-Time Dependent Characteristics of Dynamic and Isometric Muscle Actions. *Journal of Strength and Conditioning Research, 11*(4), 269-272.

Häkkinen, K., Kauhanen, H., & Komi, P. V. (1984). Biomechanical changes in the olympic weightlifting technique of the snatch and clean & jerk from submaximal to maximal loads. *Scand J Sports Sci, 6*(2), 57-66.

Häkkinen, K., & Komi, P. V. (1981). Effect of different combined concentric and eccentric muscle work regimens on maximal strength development. *J Human Mov Studies, 7*, 33-44.

Hopkins, W. G. (2014). A scale of magnitude for effect statistics. Retrieved from: http://sportsci.org/resource/stats/effectmag.html

Hornsby, W. G., Haff, G. G., Sands, W. A., Ramsey, M. W., Beckham, G. K., Stone, M. E., & Stone, M. H. (2013). Alterations in strength characteristics for isometric and dynamic mid-thigh pulls in collegiate throwers across 11 weeks of training. *Gazzetta Medica Italiana, 172*(12), 929-940.

Hubley, C. L., & Wells, R. P. (1983). A work-energy approach to determine individual joint contributions to vertical jump performance. *European Journal of Applied Physiology and Occupational Physiology, 50*(2), 247-254. doi: 10.1007/BF00422163

Kauhanen, H., Häkkinen, K., & Komi, P. V. (1984). A biomechanical analysis of the snatch and clean & jerk techniques of Finnish elite and district level weightlifters. *Scand J Sports Sci, 6*(2), 47-56.

Kawamori, N., Rossi, S. J., Justice, B. D., Haff, E. E., Pistilli, E. E., O'Bryant, H. S., . . . Haff, G. G. (2006). Peak force and rate of force development during isometric and dynamic mid-thigh clean pulls performed at various intensities. *Journal of Strength and Conditioning Research, 20*(3), 483-491. doi: 10.1519/18025.1

Khamoui, A. V., Brown, L. E., Nguyen, D., Uribe, B. P., Coburn, J. W., Noffal, G. J., & Tran, T. (2011). Relationship between force-time and velocity-time characteristics of dynamic and isometric muscle actions. *Journal of Strength and Conditioning Research, 25*(1), 198-204. doi: 10.1519/JSC.0b013e3181b94a7b

Kipp, K., Redden, J., Sabick, M. B., & Harris, C. (2012). Weightlifting performance is related to kinematic and kinetic patterns of the hip and knee joints. *Journal of Strength and Conditioning Research, 26*(7), 1838-1844. doi: 10.1519/JSC.0b013e318239c1d2

Knapik, J. J., Vogel, J. A., & Wright, J. E. (1981). *Measurement of Isometric Strength in an Upright Pull at 38cm*. Natick, Maryland.

Kraska, J. M., Ramsey, M. W., Haff, G. G., Fethke, N., Sands, W. A., Stone, M. E., & Stone, M. H. (2009). Relationship between strength characteristics and unweighted and weighted vertical jump height. *International Journal of Sports Physiology and Performance, 4*(4), 461-473.

Laubach, L. L. (1976). *Muscular strength of women and men: a comparative study*. Dayton, Ohio.

Lawton, T. W., Cronin, J. B., & McGuigan, M. R. (2012). Anthropometry, strength and benchmarks for development: a basis for junior rowers' selection? *Journal of Sports Sciences, 30*(10), 995-1001. doi: 10.1080/02640414.2012.682081

Leary, B. K., Statler, J., Hopkins, B., Fitzwater, R., Kesling, T., Lyon, J., . . . Haff, G. G. (2012). The relationship between isometric force-time curve characteristics and club head speed in recreational golfers. *Journal of Strength and Conditioning Research, 26*(10), 2685-2697. doi: 10.1519/JSC.0b013e31826791bf

Lees, A., Vanrenterghem, J., & De Clercq, D. (2004). The maximal and submaximal vertical jump: implications for strength and conditioning. *Journal of Strength and Conditioning Research, 18*(4), 787-791. doi: 10.1519/14093.1

Lehman, G. J., & McGill, S. M. (1999). The importance of normalization in the interpretation of surface electromyography: a proof of principle. *Journal of Manipulative and Physiological Therapeutics, 22*(7), 444-446. doi: 10.1016/s0161-4754(99)70032-1

McBride, J. M., Cormie, P., & Deane, R. (2006). Isometric squat force output and muscle activity in stable and unstable conditions. *Journal of Strength and Conditioning Research, 20*(4), 915-918. doi: 10.1519/R-19305.1

McCurdy, K., Langford, G. A., Cline, A. L., Doscher, M., & Hoff, R. (2004). The Reliability of 1- and 3Rm Tests of Unilateral Strength in Trained and Untrained Men and Women. *Journal of Sports Science & Medicine, 3*(3), 190-196.

McGarvey, S. R., Morrey, B. F., Askew, L. J., & An, K. N. (1984). Reliability of isometric strength testing. Temporal factors and strength variation. *Clinical Orthopaedics and Related Research, 185*(185), 301-305.

McGill, S. M., Hughson, R. L., & Parks, K. (2000). Changes in lumbar lordosis modify the role of the extensor muscles. *Clinical Biomechanics*, *15*(10), 777-780. doi: http://dx.doi.org/10.1016/S0268-0033(00)00037-1

McGuigan, M. (2011). [Discussion about body positions used in isometric mid-thigh pull testing].

McGuigan, M. R., Newton, M. J., & Winchester, J. B. (2008). Use of isometric testing in soccer players. *J Aus Strength Cond Assn*, *16*(4), 11-14.

McGuigan, M. R., Newton, M. J., Winchester, J. B., & Nelson, A. G. (2010). Relationship between isometric and dynamic strength in recreationally trained men. *Journal of Strength and Conditioning Research*, *24*(9), 2570-2573. doi: 10.1519/JSC.0b013e3181ecd381

McGuigan, M. R., & Winchester, J. B. (2008). The relationship between isometric and dynamic strength in college football players. *J Sport Sci & Med*, *7*(1), 101-105.

McGuigan, M. R., Winchester, J. B., & Erickson, T. (2006). The importance of isometric maximum strength in college wrestlers. *Journal of Sports Science & Medicine, 5*(CSSI), 108-113.

McMaster, D. T., Gill, N., Cronin, J., & McGuigan, M. (2014). A brief review of strength and ballistic assessment methodologies in sport. *Sports Medicine, 44*(5), 603-623. doi: 10.1007/s40279-014-0145-2

Murphy, A. J., & Wilson, G. J. (1996). Poor correlations between isometric tests and dynamic performance: relationship to muscle activation. *European Journal of Applied Physiology, 73*(3-4), 353-357.

Murphy, A. J., & Wilson, G. J. (1997). The ability of tests of muscular function to reflect training-induced changes in performance. *Journal of Sports Sciences, 15*(2), 191-200. doi: 10.1080/026404197367461

Murphy, A. J., Wilson, G. J., Pryor, J. F., & Newton, R. U. (1995). Isometric assessment of muscular function: the effect of joint angle. *Journal of Applied Biomechanics, 11*, 205-215.

Nuzzo, J. L., McBride, J. M., Cormie, P., & McCaulley, G. O. (2008). Relationship between countermovement jump performance and multijoint isometric and dynamic tests of strength. *Journal of Strength and Conditioning Research, 22*(3), 699-707. doi: 10.1519/JSC.0b013e31816d5eda

Painter, K. B., Haff, G. G., Ramsey, M. W., McBride, J., Triplett, T., Sands, W. A., . . . Stone, M. H. (2012). Strength gains: block versus daily undulating periodization weight training among track and field athletes. *International Journal of Sports Physiology and Performance, 7*(2), 161-169.

Pekünlü, E., & Özsu, İ. (2014). Avoiding Systematic Errors in Isometric Squat-Related Studies without Pre-Familiarization by Using Sufficient Numbers of Trials. *J Human Kinetics, 42*(1), 201-213.

Ploutz-Snyder, L. L., & Giamis, E. L. (2001). Orientation and familiarization to 1RM strength testing in old and young women. *Journal of Strength and Conditioning Research, 15*(4), 519-523.

Potvin, J. R., Norman, R. W., & McGill, S. M. (1991). Reduction in anterior shear forces on the L 4L 5 disc by the lumbar musculature. *Clinical Biomechanics, 6*(2), 88-96. doi: 10.1016/0268-0033(91)90005-B

R Core Team. (2014). R: A Language and Environment for Statistical Computing. Vienna, Austria.

Sapstead, G., & Duncan, M. (2013). Acute Effect of Isometric Mid-Thigh Pulls on Postactivation Potentiation during Stretch-Shortening Cycle and Non-Stretch-Shortening Cycle Vertical Jumps. *Medicina Sportiva, 17*(1), 7-11. doi: 10.5604/17342260.1041878

Sato, K., Bazyler, C., Beckham, G., Gray, H., Hornsby, G., Kavanaugh, A., . . . Stone, M. (2012). *Force output comparison between six US collegiate athletic teams.* Paper presented at the International Society of Sports Biomechanics, Melbourne, Australia.

Schroeder, E. T., Wang, Y., Castaneda-Sceppa, C., Cloutier, G., Vallejo, A. F., Kawakubo, M., . . . Sattler, F. R. (2007). Reliability of maximal voluntary muscle strength and power testing in older men. *Journals of Gerontology. Series A: Biological Sciences and Medical Sciences, 62*(5), 543-549. doi: 10.1093/gerona/62.5.543

Secomb, J. L., Lundgren, L., Farley, O. R., Tran, T. T., Nimphius, S., & Sheppard, J. M. (2015). Relationships between Lower-Body Muscle Structure and Lower-Body Strength, Power and Muscle-Tendon Complex Stiffness. *Journal of Strength and Conditioning Research*, 1-1. doi: 10.1519/JSC.0000000000000858

Sedliak, M., Finni, T., Cheng, S., Haikarainen, T., & Hakkinen, K. (2008). Diurnal variation in maximal and submaximal strength, power and neural activation of leg extensors in men: multiple sampling across two consecutive days. *International Journal of Sports Medicine, 29*(3), 217-224. doi: 10.1055/s-2007-965125

Selvanayagam, V. S., Riek, S., & Carroll, T. J. (2011). Early neural responses to strength training. *Journal of Applied Physiology, 111*(2), 367-375. doi: 10.1152/japplphysiol.00064.2011

SENIAM. (2014). Recommendations for sensor locations on individual muscles. from www.SENIAM.org

Seo, D. I., Kim, E., Fahs, C. A., Rossow, L., Young, K., Ferguson, S. L., . . . So, W. Y. (2012). Reliability of the one-repetition maximum test based on muscle group and gender. *Journal of Sports Science & Medicine, 11*(2), 221-225.

Sheppard, J. M., & Young, W. B. (2006). Agility literature review: classifications, training and testing. *Journal of Sports Sciences, 24*(9), 919-932. doi: 10.1080/02640410500457109

Spiteri, T., Nimphius, S., Hart, N. H., Specos, C., Sheppard, J. M., & Newton, R. U. (2014). Contribution of strength characteristics to change of direction and agility performance in female basketball athletes. *Journal of Strength and Conditioning Research, 28*(9), 2415-2423. doi: 10.1519/JSC.0000000000000547

Stone, M. H., O'Bryant, H., & Haff, G. G. (1995). *Preliminary investigation of the isometric mid-thigh pull*. Unpublished Data.

Stone, M. H., Sanborn, K., O'Bryant, H. S., Hartman, M., Stone, M. E., Proulx, C., . . . Hruby, J. (2003). Maximum strength-power-performance relationships in collegiate throwers. *Journal of Strength and Conditioning Research, 17*(4), 739-745. doi: 10.1519/00124278-200311000-00019

Stone, M. H., Sands, W. A., Carlock, J., Callan, S., Dickie, D., Daigle, K., . . . Hartman, M. (2004). The importance of isometric maximum strength and peak rate-of-force development in sprint cycling. *Journal of Strength and Conditioning Research, 18*(4), 878-884. doi: 10.1519/14874.1

Stone, M. H., Sands, W. A., Pierce, K. C., Carlock, J., Cardinale, M., & Newton, R. U. (2005). Relationship of maximum strength to weightlifting performance. *Medicine and Science in Sports and Exercise, 37*(6), 1037-1043.

Stone, M. H., Sands, W. A., Pierce, K. C., Ramsey, M. W., & Haff, G. G. (2008). Power and Power Potentiation Among Strength-Power Athletes: Preliminary Study. *Int J Sports Phys Perform, 3*(1), 55-67.

Stone, M. H., Stone, M., & Sands, W. A. (2007). *Principles and practice of resistance training*: Human Kinetics.

Tabachnick, B., & Fidell, L. (2007). *Experimental Design Using Anova*. Belmont, CA: Duxbury/Thomson.

Takano, B. (1987). Coaching optimal technique in the snatch and the clean and jerk: Part II. *Strength & Conditioning Journal, 9*(6), 52-56.

Teo, W., McGuigan, M. R., & Newton, M. J. (2011). The effects of circadian rhythmicity of salivary cortisol and testosterone on maximal isometric force, maximal dynamic force, and power output. *Journal of Strength and Conditioning Research, 25*(6), 1538-1545. doi: 10.1519/JSC.0b013e3181da77b0

Teves, M. A., Wright, J. E., & Vogel, J. A. (1985). *Performance on Selected Candidate Screening Test Procedures Before and After Army Basic and Advanced Individual Training*. Fort Detrick, MD.

Thomas, C., Comfort, P., Chiang, C.-y., & Jones, P. A. (2015). Relationship between isometric mid-thigh pull variables and sprint and change of direction performance in collegiate athletes. *Journal of Trainology, 4*, 6-10.

Thomas, C., Jones, P. A., & Comfort, P. (2014). Reliability of the Dynamic Strength Index in Collegiate Athletes. *International Journal of Sports Physiology and Performance*. doi: 10.1123/ijspp.2014-0255

Thomas, C., Jones, P. A., Rothwell, J., Chiang, C. Y., & Comfort, P. (2015). An Investigation into the Relationship between Maximum Isometric Strength and Vertical Jump Performance. *Journal of Strength and Conditioning Research*. doi: 10.1519/JSC.0000000000000866

Thorstensson, A., Sjodin, B., & Karlsson, J. (1975). Enzyme activities and muscle strength after "sprint training" in man. *Acta Physiologica Scandinavica, 94*(3), 313-318.

Vogel, J. A. (1986). *Fitness and Activity Assessments among U.S. Army Populations: Implications for NCHS General Population Surveys*. Natick, MA.

West, D. J., Owen, N. J., Jones, M. R., Bracken, R. M., Cook, C. J., Cunningham, D. J., . . . Kilduff, L. P. (2011). Relationships between force-time characteristics of the isometric midthigh pull and dynamic performance in professional rugby league players. *Journal of Strength and Conditioning Research, 25*(11), 3070-3075. doi: 10.1519/JSC.0b013e318212dcd5

Whittington, J., Schoen, E., Labounty, L. L., Hamdy, R., Ramsey, M. W., Stone, M. E., . . . Stone, M. H. (2009). Bone mineral density and content of collegiate throwers: influence of maximum strength. *Journal of Sports Medicine and Physical Fitness, 49*(4), 464-473. doi: R40092720 [pii]

Wilson, G. J., & Murphy, A. J. (1996). The use of isometric tests of muscular function in athletic assessment. *Sports Medicine, 22*(1), 19-37. doi: 10.2165/00007256-199622010-00003

Wilson, G. J., Murphy, A. J., & Walshe, A. (1996). The specificity of strength training: the effect of posture. *European Journal of Applied Physiology and Occupational Physiology, 73*(3-4), 346-352.

Winchester, J. B., McBride, J. M., Maher, M. A., Mikat, R. P., Allen, B. K., Kline, D. E., & McGuigan, M. R. (2008). Eight weeks of ballistic exercise improves power independently of changes in strength and muscle fiber type expression. *Journal of Strength and Conditioning Research, 22*(6), 1728-1734. doi: 10.1519/JSC.0b013e3181821abb

Young, W. (1995). Laboratory strength assessment of athletes. *New Studies in Athletics, 10*(1), 89-96.

Young, W., McLean, B., & Ardagna, J. (1995). Relationship between strength qualities and sprinting performance. *Journal of Sports Medicine and Physical Fitness, 35*(1), 13-19.

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Hornsby, W. G., Haff, G. G., Sands, W. A., Ramsey, M. W., Beckham, G. K., Stone, M. E., Stone, & M. H. (2013). Strength characteristics for isometric and dynamic mid-thigh pulls in collegiate throwers across 11 weeks of training. Gazzetta Medica Italiana 172(12), 929-40.

Suchomel, T. J., Beckham, G. K., Wright, G. A. (2013). Lower body kinetics during the jump shrug: impact of load. Journal of Trainology 2(2), 19-22.

Beckham, G., Miziguchi, S., Carter, C., Sato, K., Ramsey, M., Lamont, H., Hornsby, W., Haff, G., & Stone, M. (2013). Relationships of isometric mid-thigh pull variables to weightlifting performance. Journal of Sports Medicine and Physical Fitness 53(5), 573-81.

Suchomel, T. J., DeWeese, B. H., Beckham, G. K., Serrano, A. J., French, S. M. (2014). The hang high pull, a progressive exercise into weightlifting derivatives. Strength and Conditioning Journal, 36(6), 79-83.

Suchomel, T. J., Beckham, G. K., Wright, G. A. (2014). The impact of load on lower body performance variables during the hang power clean. Sports Biomechanics, 13(1):87-95.

Suchomel, T.J., DeWeese, B.H., Beckham, G.K., Serrano, A.J., and Sole, C.J. (2014) The jump shrug: A progressive exercise into weightlifting derivatives. Strength and Conditioning Journal 36(3), 43-47.

Beckham, G. K., Suchomel, T., Mizuguchi, S. (2014). Force Plate Use in Sport Science Testing. New Studies in Athletics 29(3), 25-37.

Suchomel, T.J., Beckham, G.K., and Wright, G.A. (2015). The effect of various loads on the force-time characteristics of the hang high pull. Journal of Strength and Conditioning Research. 29(5), 1295-1301.

Suchomel, T.J., Bailey, C.A., Sole, C.J., Grazer, J.L., and Beckham, G.K. (2015) Reactive strength index-modified: a comparison between six U.S. collegiate athletic teams. Journal of Strength and Conditioning Research. 29(5), 1310-1316.

Suchomel, T.J., Bailey, C.A., Sole, C.J., Grazer, J.L., and Beckham, G.K. (2015). Using reactive strength index-modified as an explosive performance measurement tool in Division I athletes. Journal of Strength and Conditioning Research. 29(4): 899-904.

Sato, K., Beckham, G. K., Caroll, K., Bazyler, C., Sha, X., Haff, G. G. (2015) Validity of a wireless device measuring velocity of resistance exercises. Journal of Trainology 4, 15-18.

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