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Relationship of Force Variables to Vertical Jumps Performance

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by
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May 2016

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Keywords: Maximal Strength, Performance Testing, Vertical Jump Performance

ABSTRACT

Relationship of Force Variables to Vertical Jumps Performance

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Hugo A. de P. Santana

The isometric mid-thigh pull (IMTP) has been cited often in the scientific literature; however, there is still a lack of agreement as to the ideal body position used during this test, and how body position impacts the relationship between IMTP performance and dynamic performance. Thus, one aim of this dissertation was to compare two different IMTP positions and correlate the kinetic outputs from each position to vertical jump (VJ) performance. Another purpose of this dissertation was analyze which method of data normalization for IMTP force variables best correlates to squat jump (SJ) and countermovement jump (CMJ) performance.

In the first study, subjects presented higher force outputs for an upright position (hip angles 145°, knee 125°) when compared to a bent position (hip angles 125°, knee 125°). However, there were no statistical differences among correlations from the two positions when correlating to VJ performance. Thus, we suggest that the upright position should be the one used for research and monitoring due to higher force values presented.

The second part of this study was to compare correlations from non-normalized and normalized data from the IMTP to SJ and CMJ. Besides non-normalized data, five common methods of normalization were used – subtracting the body mass force, dividing the forces per body mass, allometric scale, scaling by height (Ford's scale) and

scaling by Sinclair coefficient value. In general, higher value correlations were presented with the non-normalized methods for both jumps – SJ and CMJ. Therefore, when using IMTP data to correlate with VJ performance, there is no need to normalize the data.

DEDICATION

This dissertation is dedicated to my family. Without your dedication and support (in all aspects, love and financial) nothing could be accomplished. To my brother and my sister – it is hard to come out of your big shadows by being giants, but you left me footsteps that I could follow to a great path. To my nephews and my niece any caring act, goofy face or joke in Skype gave me strength to continue even being so far away. Mom and Dad, I could write here forever and still would be no words, in any language, that I could express my gratitude for everything you have done and what you really are for me – Amo vocês!

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My Brazilian friends, who became my family, thanks for making this our home. You gave me the strength when I did not have it – I have so many moments to be thankful, that I will skip and let this part to be more general. Instead of citing so many names and memories, I prefer to relive them with you in a near future time.

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CHAPTER 1

INTRODUCTION

Strength tests are widely used in sports, ergonomic and clinical practice. The goal of these tests are to assess muscle-function, monitoring for sports, rehabilitation and talent identification with valid methods (Abernethy, Wilson, & Logan, 1995; Johnston, 2014; Keogh, Weber, & Dalton, 2003). Muscle strength can be measured as maximum force (N) or torque (Nm) in a predetermined condition. Different dynamometers measuring concentric, eccentric and isometric forces have been used to measure forces, as well isokinetic devices. In recent years, the use of isometric devices has become a valuable tool in the measurement of athletes (Beckham et al., 2013; Haff et al., 2005; McGuigan & Winchester, 2008). Most of these isometric assessments involve multi-joint movements such as a squat of pulling position. There are several reasons for using these multi-joint isometric measures: 1) they are less time consuming than typical multi-joint dynamic RM tests, 2) there is a greater potential of actually achieving a maximum measure of strength when compared to typical dynamic tests, and 3) Multi-joint isometric assessments of force show stronger correlations to dynamic performance than single-joint isometric assessments (McGuigan & Winchester, 2008; Nuzzo, McBride, Cormie, & Mccaulley, 2008).

One of the more common tests used is an isometric clean pull (Haff et al., 2005). Although there is general agreement as to the value of isometric pulls there is some controversy concerning the exact positioning to achieve the best result (Beckham et al., 2012; Comfort, Jones, McMahon, & Newton, 2015). This controversy deals with a lack of consensus as to where “is” the mid-thigh position; knee and hip angles will influence where the bar will be placed and based on mathematical calculation should greatly influence the mechanical advantage of the position (Beckham et al., 2012; 2013; Comfort et al., 2015; Kawamori et al., 2006; McGuigan & Winchester, 2008). Comfort et al. (2015) indicates that a variety of positions based on knee and hip angles did not make a statistical difference in the peak forces achieved; however, Haff et al. (2005) and Beckham et al. (2012) have reported data that disagrees with these findings. In order to elucidate this problem, more research is needed to determine how positional differences contribute to the forces achieved during the IMTP. In addition, another question to be answered is whether different IMTP positions result in different relationships with dynamic muscle actions, such as vertical jump height and force variables.

However, several factors can confound the evaluation of strength tests, one intervening factor that can influence levels of strength is body mass (BM). Generally, athletes with larger BM exhibit a greater level of lean BM, and are likely able to generate greater levels of absolute force (Batterham & George, 1997; Hoffman et al., 2005; Marković & Sekulić, 2006; Nedeljkovic, Mirkov, Bozic, & Jaric, 2009; Nedeljkovic, Mirkov, Markovic, & Jaric, 2009). This can make it harder to compare different athletes and track the evolution of training when athletes change their body mass during a season. In order to solve this problem of comparing different athletes, with different body sizes (mass and height), there are several ways of normalizing data – ratio scaling, allometric scale, scaling by height, Sinclair formula (Ford, Detterline, Ho, & Cao, 2000; Jaric, Mirkov, & Markovic, 2005; Jaric, 2002; Stone et al., 2005). However, there is still a need in the literature for strength normalization values for IMTP tests yielding the best relationships to dynamic performance of vertical jumps.

CHAPTER 2

REVIEW OF LITERATURE

Isometric Mid-Thigh Pull Testing

Force can be measured as strength and can be assessed for different purposes such as to quantify the relative strength necessary for daily tasks and athletic events or to identify muscular function deficiencies, talent identification and monitor efficiency of training interventions (Abernethy et al., 1995). Strength is the “ability” to exert force against external resistance (Stone, Stone, & Sands, 2007). One common way of measuring strength is through isometric testing – single and multi-joint isometric tests can be seen in the 1960 (Chaffin, 1975). Single joint testing may be undesirable or even contraindicated in some pathological conditions of the knee joint (Palmitier, An, Scott, & Chao, 1991), probably due to differing muscle recruitment, joint and ligament stresses between multi-joint and single joint testing (Escamilla et al., 1998).

Although single joint tests are still used, some researchers have observed weak relationships between single-joint isometric tasks and multi-joint dynamic tasks, e.g. squatting performance (Baker, Wilson, & Carlyon, 1994) and bench press performance (Wilson, Murphy, & Walshe, 1996). This observation has led to the general conclusion that isometric testing is ineffective when making conclusions about dynamic muscle actions (Wilson & Murphy, 1996). However, the validity of isometric testing depends on joint angle and position specificity, which may impact the ability of the isometric tasks ability to yield information about dynamic muscle actions (Haff et al., 1997; Kawamori et al., 2006; Murphy, Wilson, Pryor, & Newton, 1995; Wilson & Murphy, 1996)

The use of multi-joint isometric muscle actions is not new as it can be noted that in the 1980's these tests were used in order to estimate preparation for job-related lifting tasks (Knapik, Vogel, & Wright, 1981; Teves, Wright, & Vogel, 1985; Vogel, 1986). Additionally, during the mid to late 90's, some researchers started reporting measures of multi-joint isometric tests and multi-joint dynamic performance in the same papers (Haff et al., 1997; Wilson, Newton, Murphy, & Humphries, 1993; Young, McLean, & Ardagna, 1995; Young, 1995). For example, isometric squats were initially used to monitor improvement on resistance training performance (Wilson et al., 1993) and correlate to sprint dynamic performance (Young et al., 1995), after that a few authors still used isometric squat testing (Blazevich, Gill, & Newton, 2002; Prue Cormie, Deane, Triplett, & McBride, 2006; McBride, Cormie, & Deane, 2006; Nuzzo et al., 2008).

One multi-joint isometric test that was first described in 1997, is the isometric mid-thigh pull (IMTP) (Haff et al., 1997). The IMTP was created to mimic the second pull of the weightlifting movements (clean and snatch) and was expected to be similar to the power position which is often considered the most athletic position in sport. Moderate to large correlations were originally reported between force-time data from the IMTP and dynamic performance of pulling motions from weightlifting and vertical jumps (Haff et al., 1997). After this first article, the use of IMTP was presented in several publications (Haff et al., 2008; Haff et al., 2005; Hori et al., 2008; Kawamori et al., 2006; Kraska et al., 2009; McGuigan, Winchester, & Erickson, 2006; McGuigan & Winchester, 2008; Stone et al., 2004; Stone et al., 2005; Stone et al., 2003; Stone, Sands, Pierce, Ramsey, & Haff, 2008). The IMTP test has been correlated to several dynamic performances, such as 1 RM Squats (McGuigan, Newton, & Winchester, 2008; McGuigan et al., 2006, Nuzzo et al., 2008), weightlifting movements (Beckham et al., 2013; Haff et al., 1997, 2005; Kawamori et al., 2006; Stone et al., 2005), countermovement jumps (Khamoui et al., 2011; Kraska et al., 2009; Thomas et al., 2015) and static jumps (Kraska et al., 2009; Thomas et al., 2015).

Harman (1993) defined strength as the force exerted under a given set of conditions, which includes posture, pattern and speed of movement. And, the posture and body positioning related to IMTP test is still an area of disagreement between different researchers. Haff et al, (1997) stated that the IMTP is performed in a position similar to second pull of clean weightlifting movement, which should show higher forces and power outputs maximizing force and power performances for the test (Haff et al., 1997). Other publications from the same group of researchers presented similar body position and higher precision on reporting knee angles (Bailey, Sato, Alexander, Chiang, & Stone, 2013; Beckham et al., 2012; Beckham et al., 2013; Haff et al., 2005; Kraska et al., 2009; Stone et al., 2004; Stone et al., 2008; Stone et al., 2005). The authors reported knee angles varying between 120° up to 145°, considering that as the optimal position for the initiation of the second pull of power clean, and the hip angles when reported were ranging between 145° and 175° or described as near vertical. This position needs to be individualized among subjects due to differences of trunk and limb lengths between subjects.

Other researchers reported to use similar knee angles (125°-135°), however they tested with more acute angles for the hips – below 140°(Kawamori et al., 2006; Leary et al., 2012; Spiteri et al., 2014). A very large portion of articles (Beckham et al., 2012; Crewther et al., 2012; Darrall-Jones, Jones, & Till, 2015; Haff et al., 2008; Haff et al., 2005; Hornsby et al., 2013; Khamoui et al., 2011; Lawton, Cronin, & Mcguigan, 2012; McGuigan, Newton, Winchester, & Nelson, 2010; McGuigan et al., 2006; McGuigan & Winchester, 2008; Nuzzo et al., 2008; Painter et al., 2012; Stone et al., 2004; Stone et al., 2005; Teo, McGuigan, & Newton, 2011; Thomas et al., 2015; West et al., 2011; Winchester et al., 2008) do not report the specific angle positions for knees and/or hips that the subjects were tested – it was simply omitted or general information was given, e.g. flat trunk and shoulders over the bar, bar at the height of the knee, bar was positioned just below the crease of the hip.

Currently, to the author's knowledge there are only two published articles that have investigated body position and how it might influence the performance during the IMTP (Beckham et al., 2012; Comfort et al., 2015). These articles present conflicting results, with Beckham et al. (2012) who reported that powerlifters produced higher peak force values in an upright position (knee angles at 125° and hip angle of approximately 145°) when compared to three different positions (floor, knee and deadlift lockout). Conversely, Comfort et al. (2015) report different findings; they tested college athletes in nine different positions with different angles for knees (120° to 150°) and hips (125° and 145°). There were no statistical differences among the positions tested causing the authors to suggest that the participants should use their own self-selected preferred position since there were no statistical differences to the other positions tested.

Therefore, due to the minimal investigation comparing positions of the IMTP testing and the different results and conclusions from the authors, there is a need to compare different IMTP positions aiming to see if there is any difference in force variables production. In addition, if there is any difference between positions how this could relate to dynamic performance tests (e.g. vertical jumps).

Vertical Jump Testing

Since early in the 20th century, the Vertical Jump (VJ) has been suggested to be used to assess human muscular performance (Sargent, 1921), and currently is one of the most common test used to measure performance (Abernethy et al., 1995; Taylor, Chapman, Cronin, Newton, & Gill, 2012) and to monitor athletes' performance (Gathercole, Stellingwerff, & Sporer, 2015). One of the reasons for the regular use of the VJ is it is simpler, easier and more affordable than most of other types of power tests (Klavora, 2000) and little familiarization is needed (Moir, Button, Glaister, & Stone, 2004). VJ testing is a regularly used method by strength and conditioning coaches and sport scientists to indirectly assess athletes' performance level.

Explosive movements, such as sprinting and change of direction are well correlated to VJ performance (Peterson, Alvar, & Rhea, 2006), thus VJ testing might be a useful tool to measure performance. In addition, VJ testing can be adapted to measure neuromuscular performance in different ways, by simply limiting starting position, restraining countermovement (Markovic, Dizdar, Jukic, & Cardinale, 2004) or adding external loads (Cormie, McBride, & McCaulley, 2008; Cormie et al., 2007; Kraska et al., 2009). Also, VJ has been suggested to be an easy way to assess levels of neuromuscular fatigue (Byrne & Eston, 2002; Gathercole, Stellingwerff, et al., 2015) and it is a reliable, non-fatiguing measurement (Cormack, Newton, Mcguigan, & Doyle, 2008; Marques et al., 2014; Moir, Sanders, Button, & Glaister, 2005; Moir, Shastri, & Connaboy, 2008).

Several sports performances that demand explosive strength and high power output such as weightlifting (Carlock et al., 2004; Fry et al., 2006; Viscaya, Viana, Fernandez Del Olmo, & Martin Acero, 2009), sprint cycling (Stone et al., 2004) have strong relationships to VJ performance. In addition, characteristics that are transferable and used in several sports, like sprinting (Berthoin, Dupont, Mary, & Gerbeaux, 2001; Bissas & Havenetidis, 2008; Bret, Rahmani, Dufour, Messonier, & Lacour, 2002; Cronin & Hansen, 2005; Peterson, Alvar, & Rhea, 2006) and change of direction (Barnes et al., 2007; Brughelli, Cronin, Levin, & Chaouachi, 2008; Peterson, Alvar, & Rhea, 2006), are also correlated with VJ.

Some dynamic strength tests have been associated with VJ. Soccer players have shown strong correlations between half squats maximal strength and VJ height (Wisløff, Castagna, Helgerud, Jones, & Hoff, 2004). Lower body strength has been shown to be linked to VJ performance variables, several authors reported that maximal dynamic strength correlate with VJ performance (Carlock et al., 2004; Haff et al., 1997, 2005; Nuzzo et al., 2008; Stone et al., 2003). In addition, several authors (Haff et al., 2005; Kawamori et al., 2006; Kraska et al., 2009; Nuzzo et al., 2008; Stone et al., 2004) showed that isometric peak forces and rate of force development have been correlated to VJ performance (height achieved and force variables from jumping). Due to the relationship between VJ performance and sports performance the VJ is often used as part of talent identification programs in some sports.

For example, in weightlifting, the VJ is capable of discriminating elite and non-elite athletes (Fry et al., 2006; Stone et al., 2005). The peak power reached in the VJ is associated with weightlifters current performance (Carlock et al., 2004). Researchers also have been looking for height, impulse, rate of force development (Bosco & Komi, 1979) and VJ power (Fry et al., 2006) and associating it to muscle fiber types. Therefore, not only height has been investigated, but also the force mechanisms associated with it.

The performance of a VJ on a force platform permits the direct measurement of the ground reaction forces produced during the movement. During a VJ, the subject has to overcome body weight and the resultant force during the action is the ground reaction force during the jump. Force–time, acceleration–time, velocity–time, displacement–time, and force-displacement curves can be calculated from the ground reaction force obtained from the force platform (Linthorne, 2001). During the second half of the 20th century, force-times curves have been used to analyzed human movement, such as sprints and motor learning characteristics (Henry, 1952; Howell, 1956), and is considered an effective method of analyses of athletic movements, such as VJ (Payne, Slater, & Telford, 1968). The use of a force-time curves can aid evaluation at different levels and training backgrounds (Cormie, McBride, & McCauley, 2009; Laffaye, Wagner, & Tombleson, 2014; Ugrinowitsch, Tricoli, Rodacki, Batista, & Ricard, 2007). Additionally, force-time curves can be used as a diagnostic tool for optimizing performance and to guide training interventions (Cormie et al., 2009; Cormie, Mcguigan, & Newton, 2010a, 2010b, 2010c; Dowling & Vamos, 1993; Gathercole, Sporer, Stellingwerff, & Sleivert, 2015; Gathercole, Stellingwerff, et al., 2015; Henry, 1952; Howell, 1956).

There are several different jumping tests that can be used to estimate explosive power. Some of the more common tests used are the Sargent VJ test (Sargent, 1921), standing long jump, standing triple jump (Horita, Kitamura, & Kohno, 1991; Izquierdo, Aguado, Gonzalez, Lopez, & Häkkinen, 1999), drop-jump (Viitasalo, Salo, & Lahtinen, 1998) and also Abalakow's Jump (Klavora, 2000). However, the two most commonly used VJ tests are the squat or static jump (SJ) and the countermovement jump (CMJ) (Markovic et al., 2004).

The SJ is initiated in a semi-squatted position and without a counter-movement. The participant using a CMJ starts in the standing position and initiates a downward (eccentric) movement just before the extension of hips, knees and ankles for the jump (concentric). The downward movement utilizes a stretch-shortening cycle mechanism of coordinated muscle action found to improve performance (Cavagna, Saibene, & Margaria, 1965). Therefore, the CMJ has been suggested as a test of the stretch-shortening cycle (Markovic et al., 2004).

Most subjects jump several centimeters higher in the CMJ when compared to the SJ, even with the same vertical pushoff range (Bobbert, Gerritsen, Litjens, & Van Soest, 1996b; Linthorne, 2001). The CMJ has been suggested to allow the muscles cross-bridges formation to occur before the propulsive phase leading to greater force production during the jump (Bobbert & Casius, 2005). Also, the amount of time of the eccentric phase (downward) of the jump, in addition to spinal reflexes activation of the pre-stretch (Bosco, 1997) leads to the concentric part beginning at a higher force that results in greater concentric force production (Bobbert, Gerritsen, Litjens, & Van Soest, 1996a) and might contribute to a better performance (greater height).

In conclusion, the VJ is a relative easy and reliable test that can be adapted to measure different neuromuscular performances and it is associated with strength and explosive movements. However, there is room to examine the relation between VJ variables and isometric force variables, and ascertain a position of testing isometric force and which method of analyzing isometric forces better correlates with VJ performance variables.

Data Normalization for Strength Tests

Physical performance tests can be confound by several factors, such as age, sex, physical fitness level, skill and body size (Abernethy et al., 1995; Jaric, 2002; Keating & Matyas, 1996). Body size is a well-recognized factor that affects both muscle strength and the outcome of a number of functional performance tests (Jaric, 2002). Strength and performance have been analyzed from a theoretical prospective to determine what role body size may play (Jaric et al., 2005; Jaric, 2002; McMahon, 1984). The comparisons between subjects starts from the point of view that the human body only differ in sizes, it is assumed that bodies have the same shape, which is commonly referred to as geometric or biological similarity (Challis, 1999; McMahon, 1984). Therefore, limb lengths should be proportional to a characteristic length measured on a subject (body height), and all areas (muscle cross-sectional area) are proportional to body height (Jaric, 2002; McMahon, 1984).

Based on the presumption of geometric similarity, some important relationships have been deduced from the effects of scale. Muscle force generating capacity is proportional to the muscle physiological cross-sectional area. Specifically, it should increase with body size in a manner that is proportional to mass$^{2/3}$. This relationship explains why muscle strength increases with body size at a lower rate than body mass or weight (Batterham & George, 1997; McMahon, 1984). Based upon this many authors use a muscle strength index based on an allometric scale (Batterham & George, 1997; McMahon, 1984; Vanderburgh & Dooman, 2000). In a different situation, the performance of some functional tests, based on muscle actions intended to support body weight under strength-demanding conditions, should be negatively related to body size (Jaric, 2002, 2003). Since body weight increases in a manner that is proportional to body mass, while the muscle force needed to overcome the body weight increases at a slower rate (proportionally to mass$^{2/3}$) the performance of this group of functional tests (load bearing tests) should be proportional to $m^{-1/3}$ (Jaric et al., 2005). In addition to the theory of geometric similarity, the use of body mass ratio in which performance test value divided by body mass does not obviate the impact of body mass because it underestimates strength values for heavier subjects (Nedeljkovic et al., 2009).

The aforementioned normalizations are based on exerting a force against external objects, e.g. different kinds of weightlifting exercises that are often applied in athletic or physical education testing (Barnekow-Bergkvist, Hedberg, Janlert, & Jansson, 1996; Haff et al., 1997; Izquierdo et al., 2001; Jensen, Freedson, & J, 1996; Stone et al., 2005), or two-hand lift or manual material handling applied in ergonomic studies (Hattori et al., 2000). Different tasks for movement performance consisting of maximum speed of body segments, such as throwing, kicking, serving (Cronin, Mcnair, & Marshall, 2001; Fry & Morton, 1991; Kraemer et al., 2000), or whole body center of mass movement (Cometti, Maffiuletti, Pousson, Chatard, & Maffulli, 2001; Jaric, Ugarkovic, & Kukolj, 2002; Kukolj, Ropret, Ugarkovic, & Jaric, 1999; Ostenberg, Roos, Ekdahl, & Roos, 1998) require a different approach. Some complex scaling methods suggested a weak relationship with performance variables for these type of tests, and allometric modelling based on geometric similarity suggests no relationship (Hill, 1950; Nevill, Ramsbottom, & Williams, 1992). So, squat jump height and countermovement jump height have been considered as a body size-independent index of muscle power and the ability to produce power (or rapid performance) in movements based predominantly on concentric actions and the stretch – shortening cycle could be partly independent (Markovic & Jaric, 2007). Also, athletic experience suggests no relationship between maximum movement velocity and body size - the fastest running, or the longest jump, or the fastest tennis or volleyball serve, are expected neither from the smallest nor from the biggest athletes (Jaric, 2002). Therefore, the performance of rapid body movements is not likely to require normalization for body size.

Another normalization method that can be used to try to equalize people with different body sizes would be height. A constant ratio was observed, for both men and women, between different classes weightlifting champions from 1993-1997 when dividing their total weightlifted by height$^{2.16}$ (Ford et al., 2000). A possible limitation of this finding is that an absolute upper limit to lateral muscle growth at a height of about 183 cm in men and 175 cm in women (Ford et al., 2000). The idea of using height as a normalization method is based upon the hypothesis that athletes would have achieved maximum or near-maximum muscle fiber size (i.e., cross section) with maximum strength being directly related to the number of muscle fibers in parallel (Ford et al., 2000). Because final muscle fiber number, cross-sectional area and bone length appear to be determined as a result of commonly shared maturation factors (Taylor & Wilkinson, 1986) the final number of muscle fibers and cross-section area should be strongly correlated with height.

One type of normalization that occurs in sports (weightlifting) is the Sinclair Coefficient. The Sinclair Coefficient formula, a polynomial equation, is a method used in weightlifting to compare athletes' performance among different weight classes, it is updated every 4 years, and appears to have a reasonable theoretical foundation when measuring compare exercises from the weightlifting (Stone et al., 2005). The use of Sinclair coefficient formula as a normalization method might be limited to few exercises (e.g. weightlifting movements), however there is a paucity of research supporting the use of this coefficient as a normalization method for non-weightlifters.

Thus, there are several different methods of analyzing force production in order to equalize performance for different body sizes people, however there is still a need to study which method might be more appropriate to normalize IMTP variables in relation to dynamic performance of jumps.

CHAPTER 3

THE IMPACT OF BODY POSITION DURING THE ISOMETRIC MID-THIGH PULL ON THE RELATIONSHIP BETWEEN FORCE PRODUCTION AND DYNAMIC PERFORMANCE OF JUMPING

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Abstract

The isometric mid-thigh pull (IMTP) has been cited often in the scientific literature; however, there is still a lack of agreement as to the ideal body position used during this test, and how body position impacts the relationship between IMTP performance and dynamic performance. The aim of this study was to compare two different IMTP positions and correlate the kinetic outputs from each position to vertical jump (VJ) performance. Twenty-two male subjects participated on two different testing days separated by at least 72 hours. Subjects performed Squat Jumps and Countermovement Jumps; and two positions for the IMTP (Upright position – 125° knee angle and 145° hip angle, and bent position - 125° knee angle and 125° hip angle). All force-time curves were analyzed using custom LabVIEW software. All IMTP data were analyzed with paired samples t-tests in order to compare the force-time curve results from the two pull-positions. Pearson product moment correlations were used to determine relationships between the dynamic and isometric performance variables. Isometric Peak Force, Force at 50, 90 and 200ms, Rate of force development from 0-200ms, as well as impulse from 0-200ms were significantly greater (*p*<0.008) during the upright position. However, both positions resulted in comparable correlations with dynamic performance variables.

Keywords: Maximal Strength, Performance Testing, Vertical Jump Performance

Introduction

Neuromuscular function can be evaluated with several types of tests, including both dynamic and isometric methods. Maximal strength is a worthwhile monitoring test characteristic athletes (19) and is commonly tested dynamically with the use of a 1 repetition maximum (RM). However, 1 RM tests are considered time consuming and might cause fatigue, especially considering the method of load increment. Isometric tests using force platforms to examine peak force (PF) and force related variables, such as rate of force development (RFD), have been suggested to be an advantageous method because of its time efficiency and the ability to perform a more detailed analysis of the athletes force production capacity when compared to typical non-instrumented dynamic tests such as the 1RM. As a result of these advantages, the isometric mid-thigh pull (IMTP) is a test that has increasingly been used as a monitoring or testing tool among researchers and strength coaches (1,5,7,12,17,22,23). One factor making the IMTP test a more attractive test is that there are large relationships between the performance during the IMTP and other dynamic performance tests including 1RM strength measures, jumping performance and sprint performance (7,20,22,23).

The IMTP test was initially created to mimic the power position or initiation of the second pull during weightlifting movements, such as the clean and snatch (7). This position was originally selected because in weightlifting it is the position during the pulling motion producing the highest forces and velocities (10). This basic position can be observed in a variety of sporting movements such as sprinting, jumping and changing directions. However, there appears to be some debate as to which body position optimizes IMTP performance. Some studies set ranges from 120° to 135° for knee angles and 140° to 150° for hip angles (1,2,6,10,13,22), and there are a few studies which for the knee and hip angles are not even reported (17,18). Additionally, a few studies (2,5) are in disagreement as to which positions produce the best results when using the IMTP.

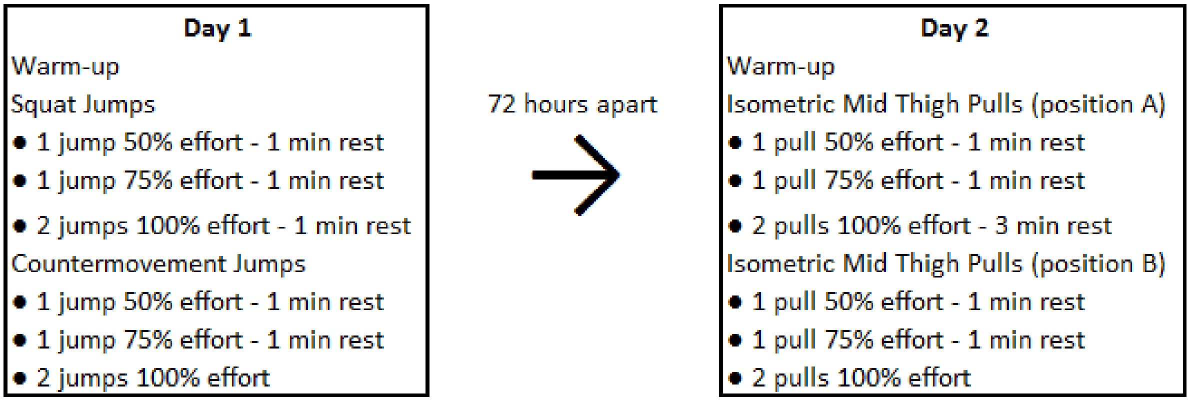
The noted discrepancies in the scientific literature regarding body position during the IMTP may lead to variability in the reliability of the test and result in difficulties in comparing athletes tested with different methodologies. These differences measured values may ultimately impact the interpretation of the data collecting during the IMTP test. It is possible that differences in body position resulted in the lack of agreement in the scientific literature in regard to the relationship between the IMTP force variables and dynamic performance (7,13,18,23).

Therefore, the purpose of this study was to compare the force-time curve variables generated during two different common used IMTP body positions. A secondary purpose was to determine the impact of these body positions on the relationship between isometric force values and jumping performance to determine if body position impacts the relationship between the isometric and dynamic performances.

Methods

Experimental approach to the problem

This study was designed to investigate differences in isometric force characteristics between two positions of the IMTP and the relationships between these variables and maximal Vertical Jump (VJ) performance (fig 1). Maximal isometric strength was selected as it provides an efficient measure of maximal strength in a variety of populations (7,15,18). The squat jump (SJ) and countermovement jump (CMJ) were selected as these tests are commonly used to assess VJ performance (20,25). The IMTP tests and jumping tests were performed on different days, at least 72 hours apart, and the subjects were asked to maintain a consistent dietary intake and to avoid any intense or high volume exercise 48 hours before both testing sessions; subjects were questioned before testing to ensure this occurred.



Day 1

Warm-up

Squat Jumps
- 1 jump 50% effort - 1 min rest
- 1 jump 75% effort - 1 min rest
- 2 jumps 100% effort - 1 min rest

Countermovement Jumps
- 1 jump 50% effort - 1 min rest
- 1 jump 75% effort - 1 min rest
- 2 jumps 100% effort

Day 2

Warm-up

Isometric Mid Thigh Pulls (position A)
- 1 pull 50% effort - 1 min rest
- 1 pull 75% effort - 1 min rest
- 2 pulls 100% effort - 3 min rest

Isometric Mid Thigh Pulls (position B)
- 1 pull 50% effort - 1 min rest
- 1 pull 75% effort - 1 min rest
- 2 pulls 100% effort

Figure 3.1. Study design. The isometric mid thigh pull position were used randomly, one position was 125° knee angle and 125° trunk angle, the other one was 125° knee angle and 145° trunk angle.

Participants

Twenty-two males (age of 24.9 ± 3.2 years old, height 177.8 ± 6.9 cm, body mass 80.2 ± 10.4 kg) volunteered to participate in this study. Subjects had different sports backgrounds and different resistance training background, ranging from zero to over 8 years of resistance exercise. Twenty-four hours prior to participation, all subjects were informed of study procedures and screened for any injuries or contraindications to perform maximal strength tests. Each participant then read and signed informed consent documents according to procedures outlined by the University Institutional Review Board.

Procedures

All participants performed SJ followed by CMJ in one session and three to four days later they performed an IMTP in two different randomized positions. On each testing day, participants performed a standardized warmup consisting of 2 minutes of cycling at 50 watts at 60 RPM, followed by 6 repetitions of forward walking lunges, reverse walking lunges, side lunges, straight leg march, and quadriceps stretching, then 5 bodyweight squats and 5 ballistic bodyweight squats - used in other studies (7,17).

During the jump test session, the subjects performed unloaded SJ and CMJ. Unloaded trials were completed while subjects held a PVC pipe (< 1 kg) just beneath the 7th cervical vertebrae behind the neck. A 90° knee angle, measured with a goniometer, was used as the starting position for the SJ. After standing on two adjacent force plates (45.5 cm x 91 cm, RoughDeck HP; Rice Lake Weighing Systems), the subjects were instructed to assume the “ready position,” by descending to the 90° knee angle. This position was held for a 3-second count and then they jumped. Participants jumped with 50% and 75% of perceived maximum effort as a specific warm-up, after which, they performed two maximum SJ. A SJ was determined to be successful if there was no observable countermovement. If so, another trial was given to the participant. After the completion of the two successful unloaded SJ trials, the same basic procedure (50%, 75% and two 100% jumps) was used for the CMJ test. In this test, countermovement depth (drop) was self-selected. The average of the two maximum jumps was used for data analysis. Rest between all jump trials and types was one minute.

During the second testing session, the participants performed the IMTP in a custom power rack (Sorinex, Irmo, SC) that allows the bar to be fixed at any height. Subjects stood on two adjacent force plates (45.5 cm x 91 cm, RoughDeck HP; Rice Lake Weighing Systems), in two separate positions (See Table 3.1). The hip angle changed between positions. The difference in angles was designed to represent the more bent over body position used in some studies (5,15–17) or an upright position (1,6,7,13,22). The body positions were measured using hand goniometry and confirmed by video analysis.

Table 3.1: Set angles for each isometric mid-thigh pull measured by goniometer before pulling.

	Hip Angle (degrees)	Knee Angle (degrees)
POS1 (Upright)	145	125
POS2 (Bent)	125	125

Both positions were tested within a single testing session. The order of pulls for each subject was randomized with three minutes of rest being used to separate the testing of each position. Prior to performing each pull position a specific warm-up which required the participants to perform two efforts with 50% and 75% of perceived maximum effort separated by one minute (2). Two minutes of rest was given between each maximal effort pull. In order to ensure there was minimal slack in the body before initiation of the pull, participants were instructed to use a very small amount of pretension (1). Once in position (verified by viewing the athlete and stability of the force trace), participants received a countdown to begin the pull, and then were instructed when to stop in accordance with previous methods (1,7). For all maximum effort pulls, participants received substantial encouragement from the investigators in order to ensure a maximal effort was achieved (3). Before each pull, participants were instructed to “pull as fast and hard as possible” to maximize rate of force development (7). Subjects pulled on the bar until maximal efforts to ensure peak force production occurred (verified by the force tracing).

A minimum of two pulls was performed at each position. A third trial was performed when there was a difference greater than 250N in peak force between pulls 1 and 2, or if any visible countermovement was noticed (observable by the investigators or greater than ~200N on the force trace)(13).

Analog data from the force plate were sampled at 1000 Hz (DAQCard-6063E, National Instruments), amplified and low-pass filtered at 16 Hz (Transducer Techniques, Temecula, CA). 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).

Force-time curve analysis

The following variables were measured from the force time curve generated during each IMTP: peak force (PF), force at 50ms (F50), force at 90ms (F90), force at 200ms (F200), impulse 0-50ms (IMP50), impulse 0-90ms (IMP90), and impulse 0-200 (IMP200). From the vertical jumps: jump height (JH), PF, peak velocity (PV), peak power (PP), force at peak power (F@PP), velocity at peak power (V@PP) were the variables extracted from the force-time curve.

Statistical analysis

Prior to all statistical analyses, data were screened for within session test-retest reliability, outliers and normality. Reliability was assessed using intraclass correlation (ICC), a paired t-test and coefficient of variation (CV), confidence interval (CI) was reported. A paired t-test in conjunction with a Bonferroni adjustment was used to avoid the inflation of type I error was used to analyze differences between the bent and upright positions (8). The following descriptors for the effect size were used: 0-0.2 as trivial, 0.2-0.6 as small, 0.6-1.2 as moderate, 1.2-2.0 as large and 2.0-4.0 as very large (4). *Pearson's* product moment correlations were used for estimation of relationships between each pull variable and jumping variables, for both pulling positions and both jumps (SJ and CMJ). A Fisher's *r* to *Z* transformation was used (14) to check for any statistical differences among correlations (21). In addition, the total number of correlations for each position was used to check if there was a position that had a higher percent of higher correlations.

Results

The IMTP variables PF, F50, F90, F200, RFD200, IMP200 for both pulling positions were considered adequately reliable for later analysis – ICC values ranging from 0.93-0.99 for upright position and 0.78-0.96 for bent position and, group CV from 22.7-35.6% and 19.8-36.5%, respectively, CI are presented in table 2. The CV between trials show lower percentages for all variables for the upright position (2.3% to 11.8%)

than bent position (4.2% to 17.3%) (figure 2). Jump Height, PF, PP and F@PP were reliable in both jumps for further analysis (ICC 0.72-0.98, group CV 11.2-18.1%, CV between trials 2.1-12.0%); however, PV and V@PP were reliable only for the CMJ (CMJ ICC 0.957-0.958, group CV 7.0-7.7%, CV between trials 1.7-1.8%, SJ ICC 0.58-0.65, group CV 6.8-6.9%, CV between trials 4.7-5.3% CI presented in table 3).

The upright position produced statistically greater means for the selected variables with small to moderate effect size (table 2). Descriptive values of SJ and CMJ are presented on table 3. The two positions produced mostly strong correlations (table 4); there was no significant differences among all correlations between different pulling positions to dynamic performance of jumps (Fisher's *r* to *Z* transformation) (table 5). The upright position had higher correlations values for 55% of the total correlations against 41.7% of the bent position.

Table 3.2.Descriptive data of PF, F50, F90, F200, RFD200 and IMP200 for bent and upright position on the Isometric Mid-Thigh Pull Test.

Positions	PF (N)	F50 (N)	F90 (N)	F200 (N)	RFD200 (N·s^{-1})	IMP200 (N·s)
Bent	3410 ±687	1546 ±313	1846 ±405	2386 ±482	5127 ±1671	380 ±79
CI	3158 – 3662	1431 – 1661	1697 – 1995	2209 – 2563	4514 – 5740	351 – 409
Upright	4090* ±977	1695* ±428	2130* ±597	2831* ±762	6911* ±2455	435* ±117
CI	3732 – 4448	1538 – 1852	1910 – 2349	2551 – 3111	6010 – 7812	392 – 478
Effect Size	0.81	0.40	0.56	0.70	0.85	0.56

CI: 90% Confidence Interval, PF: Peak force, F50: force at 50ms, F90: force at 90ms, F200: force at 200ms, RFD200: rate of force development from 0 to 200ms, IMP200: impulse from 0 to 200ms. * p<0.008 between upright and bent positions.

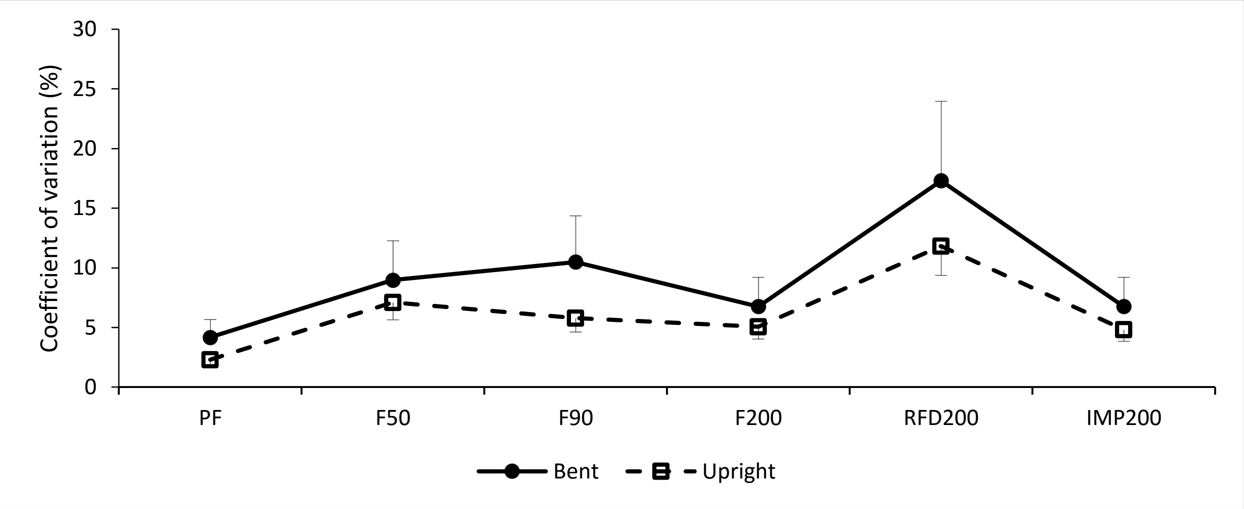


Figure 3.2. Coefficient of variation between trials with 90% confidence limits.

PF – Peak force, F50 – force at 50ms, F90 – force at 90ms, F200 – force at 200ms, RFD200 – average rate of force development 0- 200ms, IMP200 – impulse at 200ms.

Table 3.3. Descriptive data of JH, PF, PP, F@PP, PV and V@PP for Squat and Countermovement Jumps.

Jumps	JH (m)	PF (N)	PP (W)	F@PP (N)	PV (m·s^{-1})	V@PP (m·s^{-1})
SJ	0.29 ±0.05	1857 ±273	4179 ±751	1760 ±254		
CI	27.2 – 30.8	1757 - 1957	3903 – 4455	1667 – 1853		
CMJ	0.34 ±0.05	1927 ±226	4401 ±713	1739 ±246	2.8 ±0.2	2.5 ±0.2
CI	32.2 – 35.8	1844 - 2010	4139 – 4663	1649 – 1829	2.72 – 2.87	2.43 – 2.57

CI: 90% Confidence Interval, JH: Jump height, PF: peak force, PP: peak power, F@PP: force at peak power, PV: peak velocity, V@PP: velocity at peak power.

Table 3.4.Correlations of force variables between upright and bent position.

		Upright					
		PF	F50	F90	F200	RFD200	IMP200
Bent	PF	.86					
	F50		.92				
	F90			.88			
	F200				.92		
	RFD200					.76	
	IMP200						.93

PF: Peak force, F50: force at 50ms, F90: force at 90ms, F200: force at 200ms, RFD200: rate of force development from 0 to 200ms, IMP200: impulse from 0 to 200ms.

Table 3.5. Correlations of force variables of the IMTP two positions (bent and upright) to dynamic performance variables of Squat Jump and Countermovement Jump.

		Squat Jumps				Countermovement Jumps					
		JH	PF	PP	F@PP	JH	PF	PV	PP	F@PP	V@PP
Bent	PF	0.08	0.62*	0.53*	0.63*	0.08	0.62*	0.08	0.54*	0.58*	0.06
	F50	0.56*	0.69*	0.79*	0.74*	0.38	0.68*	0.31	0.82*	0.77*	0.26
	F90	0.53*	0.73*	0.78*	0.77*	0.39	0.70*	0.32	0.82*	0.77*	0.26
	F200	0.46*	0.72*	0.75*	0.76*	0.37	0.64*	0.28	0.76*	0.70*	0.25
	RFD200	0.19	0.46*	0.42	0.49*	0.23	0.35	0.16	0.40	0.36	0.16
	Imp200	0.53*	0.72*	0.78*	0.77*	0.40	0.69*	0.32	0.82*	0.76*	0.27
Upright	PF	0.24	0.62*	0.61*	0.65*	0.19	0.53*	0.18	0.60*	0.59*	0.16
	F50	0.58*	0.71*	0.81*	0.76*	0.47*	0.59*	0.40	0.82*	0.69*	0.38
	F90	0.58*	0.68*	0.76*	0.72*	0.51*	0.51*	0.42	0.78*	0.64*	0.40
	F200	0.53*	0.62*	0.71*	0.67*	0.44*	0.49*	0.35	0.70*	0.59*	0.34
	RFD200	0.37	0.40	0.46*	0.45*	0.37	0.25	0.26	0.44*	0.33	0.26
	Imp200	0.57*	0.66*	0.76*	0.71*	0.49*	0.53*	0.40	0.76*	0.63*	0.38

PF: Peak force, F50: force at 50ms, F90: force at 90ms, F200: force at 200ms, RFD200: rate of force development from 0 to 200ms, IMP200: impulse from 0 to 200ms, JH: Jump height, PP: peak power, F@PP: force at peak power, PV: peak velocity, V@PP: velocity at peak power, *correlation is significant ($p<0.05$).

Discussion

One of the main findings in this study was the statistical differences in PF, F50, F90, F200, IMP200 results between upright and slightly bent positions. The upright position showed higher values in all variables compared to bent position with small to moderate effect sizes (9). The noted differences in force production capacity between the two positions tested in the present study offer insight into the need for standardizing body position during the IMTP test. If body position is not standardized, then it is possible that the data generated during the IMTP test could impact the maximal force generated during the test and cause challenges for interpretation of test results from different studies.

The differences noted in the present study may partially explain the current discrepancies found in the scientific literature when comparing data collected in different laboratories (7,17,18,22). In contrast to the present findings, Comfort et al. (2015) reported no difference in force production when comparing IMTP positions. However, Comfort et al. (2015) tested various positions (nine positions in a day), although the positions were randomized, the high number of trials, possibly inducing fatigue, may also be one of the reasons why the force levels were lower than the results of this study.

However, despite the upright position producing higher force related values, the two positions did not impact the correlations with jump variables. Thus, if the athletes are already being monitored using a bent position, apparently there is no need to change to an upright position when aiming to correlate with vertical jump. Nevertheless, it should be noted that the upright position had a higher percentage of greater correlation with the jump variables than the bent position.

In addition, the upright position generally produced higher ICCs and lower values for CV between trials for all variables (PF, F50, F90, F200, RFD 200 and IMP200), appearing to be more reliable when retesting, hence the upright position may be the preferred position when using the IMTP for researches and athlete monitoring that are to be implemented. This position should be considered because other than showing higher values in a large number of variables presented in this study, and the tendency of producing large correlations for most variables, it is similar to the power position in weightlifting movements (1,7,13). Also, it represents a position that many athletes use in producing powerful movements such as tackling (e.g. Rugby, American Football), jumping, sprinting and change of direction (1). A mechanical advantage (better leverages) occurs for the upright position favoring higher vertical force application.

Large (0.50-0.69) correlations were found between isometric PF and dynamic PF, PP, F@PP for both jumps; large and very large (0.70-0.89) correlations were shown between isometric values of F50, F90, F200, IMP200 and dynamic performance of JH, PF, PP and F@PP for both static and countermovement jumps. The lack of statistical significant correlation between JH and isometric PF values agree with other findings (12,20,23,24). One possible reason for that might be the time to achieve peak force for IMTP being longer than time to apply forces for the jumps.

The present study indicates that measurements using the upright position can be a superior to the bent position. Therefore, it is suggested that the upright position should be used in monitoring athlete tests. Additionally the data indicate that when using IMTP tests, not only Peak Force values should be used, but also RFD and force values at shorter periods (50, 90, 200ms) in order to provide a more complete picture of athlete performance.

Practical Applications

These findings support the idea that strength characteristics (force, impulse, RFD) measurements derived from the isometric mid-thigh pull should correlate well with jumping performance, not only jumping height but also with dynamic peak force, peak power and force at peak power. Additionally, coaches and sport scientists should regularly examine early periods of the force-time curve during isometric and dynamic performance as these values can provide a broader more complete picture of the athletes' capabilities. Hence, strength coaches should continue focusing on strength and power resistance exercises to enhance dynamic, field performance of jumping and sprinting. Furthermore, the upright pull testing position appears to provide superior results, particularly for force and RFD values.

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CHAPTER 4

NORMALIZATION OF ISOMETRIC MID-THIGH PULL FORCE VALUES AND SQUAT (STATIC) JUMP PERFORMANCE

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Abstract

Strength tests have great value for coaches, however to compare different athletes with different body sizes might need data normalization. The purpose of this study was to analyze which method of data normalization for isometric mid-thigh pull (IMTP) force variables best correlates to squat jump (SJ) performance. One hundred and forty eight athletes participated in this study (age 20.3±1.3y, height 176±10cm, and weight 75.4±13.1 kg). The athletes completed a standardized warm-up, and then performed a SJ (starting at 90° knee angle measured by a goniometer before trials) on a force-plate, followed by an IMTP test. The IMTP force variable (peak force, force at 50ms, 90ms, 200ms and impulse from 0-200ms) data were normalized with the following methods: body mass (BM) ratio, force minus BM, allometric scale, Ford’s height scale and Sinclair Coefficient scale. Non-normalized data and normalized data were correlated to SJ performance variables (jump height, PF, peak power, peak velocity, force at peak power, velocity at peak power). Non-normalized correlation values presented overall higher grouped data (55% to 100% higher correlation values) than other methods of normalization. Therefore, IMTP absolute variables have positive moderate to large correlations to SJ performance and there is no need to normalize data when correlating both variables.

Key-words: Testing, Strength, dynamic performance

Introduction

Due to the importance of strength as a primary biomotor ability, many coaches and sport scientists perform tests that are specifically designed to give insight into athletes strength capacities (7,23). Physical performance tests, such as the Isometric Mid-thigh Pull (IMTP) and vertical jumps, have been used to assess muscle function, evaluate success of training and rehabilitation, evaluate performance capabilities for sport and provide normative data for groups of subjects (1,11,14,16,24). However, a number of factors, including body size, may exert a confounding effect on the evaluation of the relationship of these tests results.

Typically individuals who have an higher absolute body mass (BM) are often stronger (absolute values) than their lighter counterparts (2,11,16,19,20,22). Because of this inter-individual difference, it is very difficult to compare strength levels between different individuals of divergent sizes. One strategy to deal with this phenomenon is to use a normalization procedure to allow athletes to be compared to another one. However, lack of normalization or inconsistency in normalization methods can be found in the scientific literature when examining strength tests (1,13,14). Even though there is limited data looking at the effect of normalization there are several methodologies that have been proposed as tools for normalization of strength test results (3,14,16,24).

In the current scientific literature, several normalization methods have been presented including: ratio scaling (i.e. dividing by bodymass), allometric scaling with body mass (i.e. accounting for dimensionality), and allometrically scaling with the use of body height (8,13,14,24). Even though there are several methods suggested for normalization in the scientific literature to the authors' knowledge there is a lack of studies using normalization methods with the IMTP. Specifically, there are a minimal number of studies, which examine the impact of normalization on the relationship of IMTP variables to sports performance assessments such as the vertical jump.

Therefore, the aim of this study was to determine if the normalization method impacts the relationship between IMTP force-time curve data and squat jump (SJ) performance.

Methods

Experimental approach to the problem

This study was designed to analyze normalization methods for IMTP force variables in relation to maximal vertical jump (VJ) performance. Maximal isometric strength was selected as it provides efficient measures of maximal strength in a variety of populations (10,17,18), and also it is possible to trace force for each moment of the force-time curve. The SJ was selected because it is commonly used to assess VJ performance (21,25) without using a stretch-shortening cycle. A cross-sectional study using SJ and IMTP were performed on the same day (fig. 1) aiming to see the relationship between force data and normalization between tests. The athletes had anthropometric values measured and then performed a standard warmup followed by SJ tests and IMTP.

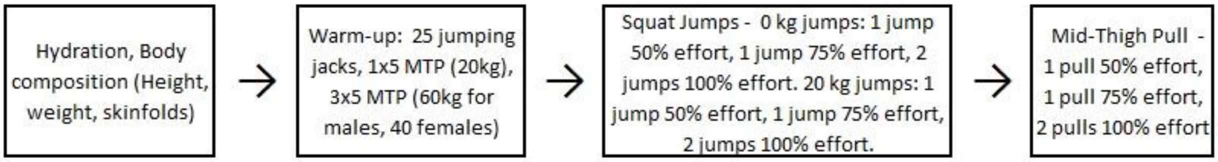

Figure 4.1. Study design.

Participants

Seventy-five male athletes and seventy-three females athletes (age 20.3±1.3y, height 176±10cm, and weight 75.4±13.1 kg) participated in this study. The participants were Division I NCAA student athletes from several sports: baseball, soccer, basketball, track and field, tennis, softball, volleyball. All athletes were informed of testing procedures previous to the start the testing. Testing was part of a regular athlete monitoring program performed just before the beginning of their competitive season and the athletes were already familiarized with testing that they had performed in previous years. The process was performed according to procedures outlined by the University Institutional Review Board.

Procedures

All athlete testing occurred on one day. This testing included: hydration, body weight measurement, unloaded and loaded SJs and IMTP testing. Upon arrival, athletes underwent a standardized warm-up: 25 jumping jacks, followed by 1 set of 5 reps of the dynamic mid-thigh pulls with an unloaded bar (20 kg), and 3x5 with either a 60 kg (for males) or 40 kg (for females) – previous unpublished data indicates that would be an average of 60 to 70% of the power clean for this population. Jumps were completed on force plates (91 cm x 45.5 cm Roughdeck HP, Rice Lake, WI) while ground reaction force data were collected at sampling frequency of 1,000 Hz.

Athletes completed warm-up and familiarization trials before maximal effort jump and loads (0kg, 20kg) at 50 and 75% of perceived maximal effort. In an effort to diminish any performance contributions coming from an arm swing, unloaded trials were completed while athletes held a PVC pipe just beneath the 7th cervical vertebrae behind the neck. During loaded conditions, a 20 kg weightlifting bar was used. Loaded jump conditions were included to simulate fatiguing situations as well as to quantify athlete responses to an external load (15).

A 90° knee angle was used as the starting position for the SJ. This angle was measured previously with a goniometer. After the athletes stood on the force plate, they were instructed to assume the “ready position,” by descending to the 90° knee angle, previously measured. This position was held for 2-3 seconds and then the athlete was instructed to jump. A successful SJ included no observable countermovement on the force trace registered by computer; if a countermovement occurred, the athlete would perform an additional jump. Athletes completed two successful jumps for each load condition and the average was used for data analysis. Rest between jump trials was approximately one minute.

The IMTP was chosen for the evaluation of strength because it is a multiple joint assessment that has been shown to relate to jumping performance (5,10). This test took place in a power rack that is custom-designed and incorporates a dual force plate setup (two 91 cm x 45.5 cm Roughdeck HP, Rice Lake, WI). The sampling frequency for all ground reaction force data was set at 1,000 Hz. Individual bar heights were set which corresponded to a knee angle of 125±5° and the trunk at the upright position, similar to the second pulling position from weightlifting exercises (4). In order to ensure grip with the bar was maintained during all trials the athlete’s used standard weightlifting straps and were further reinforced with the use of athletic tape in accordance with previously published research (Haff et al. 1997). Prior to the performance of all maximal effort trials, warm-up trials of 50 and 75% of perceived effort was completed. During maximal effort trials, athletes were instructed to "pull as fast and as hard as possible" in order to maximize the rate of force development (RFD) and maximum force (10). Two trials were completed and data was averaged for analysis. Similar to the SJ, an observable countermovement on force-trace for the IMTP would render the trial unsuccessful, and the athletes would do another pull. If the PF was different from trial 1 by values greater than 250 N, another trial was also performed (15).

Analog data from the force plate were sampled at 1,000 Hz (DAQCard-6063E, National Instruments), amplified and low-pass filtered at 16 Hz (Transducer Techniques, Temecula, CA). All force-time curves were digitally filtered using a 4th order Butterworth low-pass filter at 40 Hz and analyzed using a custom LabView program (LabView 2010, National Instruments).

Analysis

The ground reaction force data from IMTP, such as Peak Force (PF), Force at 50ms (F50), Force at 90ms (F90), Force at 200ms (F200) and Impulse from 0-200ms (IMP200), were collected and then analyzed in six different ways: non-scaled (raw force values), force values minus body mass in Newtons (N), scaled to body mass (F divided by BM), allometric scale ($F/BM^{2/3}$), ford's height scale ($F/Height^{2.16}$), Sinclair value scale (force times Sinclair coefficients for the Olympiad 2013-2016). Those values were correlated (Pearson's correlation) with jumping performance: Jump Height (JH) – calculated by flight time; jumping PF, peak velocity (PV), peak power (PP), force at peak power (F@PP) and velocity at peak power (V@PP) were the variables extracted from the force-time curve. The correlations were categorized according to Hopkins (2002), as

0.0-0.1 trivial, 0.1-0.3 small, 0.3-0.5 moderate, 0.5-0.7 large, 0.7-0.9 very large, and 0.9-1.0 nearly perfect. A comparison of correlations, Fisher's test *r* to *Z* transformation, was used to check for any statistical differences among correlations. The total number of correlations for each method was used to check if any method had a higher percent of higher correlations than the non-normalized method. Prior to statistical analysis, data were screened for within session test-retest reliability, outliers and normality. Reliability was assessed using ICCs and CV, 90% of CI was reported.

Results

Values of JH, PF, PV, PP, F@PP and V@PP, for the two conditions of SJ, were considered adequately reliable for analysis (ICC ranging from 0.92-0.99, CV between trials 2.9-7.7% and group CV from 10.4-30.0%). The IMTP values of PF, F50, F90, F200 and IMP200 without normalization and normalized were considered reliable – ICC 0.90-0.99, CV between trials 3.1-10.0% and group CV 21.5-31.2%, the data for Force values minus the BM which had higher group CV 29.8-55.8%. There were no statistical differences between the two trails for any of the variables collected. The high CV values were expected due to having a large non-homogenous group.

Descriptive data for the SJ and pulls are presented in tables 1 and 2. The correlations between IMTP values – non-scaled, values minus BM, scaled to BM, allometric scale, Height scale, and Sinclair scale, to all SJ variables showed higher values for non-normalized method (tables 3 through 8). The non-normalized method presented overall higher correlations values, when grouped 67% of all correlations from non-normalized were higher than the data subtracting the body mass force, 100% than the normalizing by dividing per BM, 93% higher than the allometric scale, 100% higher than Ford's height and 55% higher than the Sinclair coefficient scale.

Table 4.1. Descriptive data from Squat Jumps.

		JH (m)	PF (N)	PV (m·s^{-1})	PP (W)	F@PP (N)	V@PP (m·s^{-1})
SJ 0Kg	Mean	0.29	1606.7	2.55	3500.1	1522.0	2.28
	SD (±)	0.07	395.4	0.28	1016.3	363.9	0.24
	CI	0.28 - 0.30	1552.9 - 1660.5	2.51 - 2.59	3361.8 - 3638.4	1472.5 - 1571.5	2.25 - 2.31
SJ 20Kg	Mean	0.22	1735.4	2.26	3449.7	1659.5	2.06
	SD (±)	0.06	401.8	0.29	1036.9	376.4	0.25
	CI	0.21 - 0.23	1680.7 - 1790.0	2.22 - 2.30	3308.6 - 3590.8	1608.3 - 1710.7	2.03 - 2.09

Note: SJ: Squat jump, CI: 90%Confidence interval, JH: Jump height, PP: peak power, F@PP: force at peak power, PV: peak velocity, V@PP: velocity at peak power.

Table 4.2. Descriptive data from the isometric mid-thigh pulls, non-normalized and normalized methods.

		PF (N)	F50 (N)	F90 (N)	F200 (N)	IMP 200 (N·s)
Non-normalized	Mean	3606.4	1175.3	1507.1	2349.3	320.2
	SD (±)	943.6	309.5	471.0	703.0	93.3
	CI	3478.0 – 3734.7	1133.2 – 1217.4	1443.0 – 1571.2	2253.6 – 2444.9	307.5 – 332.9
Subtracted BM	Mean	2867.1	436.0	767.8	1609.9	322.0
	SD (±)	855.5	243.3	405.4	628.5	125.7
	CI	2750.7 – 2983.5	402.9 – 469.1	712.6 – 822.9	1524.4 – 1695.4	304.9 – 339.1
Divided by BM	Mean	47.7	15.6	19.9	31.0	4.2
	SD (±)	8.6	3.1	4.8	6.9	0.9
	CI	46.5 – 48.8	15.2 – 16.0	19.2 – 20.6	30.0 – 31.9	4.0 – 4.3
Allometric	Mean	201.0	65.6	83.9	130.8	17.8
	SD (±)	39.3	13.6	21.5	31.1	4.1
	CI	195.6 – 206.3	63.7 – 67.4	81.0 – 86.8	126.6 – 135.0	17.2 – 18.4
Ford's Height	Mean	1058.9	346.3	443.0	688.9	94.1
	SD (±)	222.1	79.8	122.2	168.9	23.3
	CI	1028.7 – 1089.1	335.4 – 357.2	426.4 – 459.6	665.9 – 711.9	90.9 – 97.3
Sinclair Coefficient	Mean	4480.6	1461.5	1871.9	2917.6	397.7
	SD (±)	1004.1	337.1	524.1	769.5	102.3
	CI	4344.0 – 4617.2	1415.6 – 1507.4	1800.6 – 1943.2	2812.9 – 3022.3	383.8 – 411.6

Note: CI: 90%Confidence Interval, Peak force, F50: force at 50ms, F90: force at 90ms, F200: force at 200ms, IMP200: impulse from 0 to 200ms.

Table 4.3. Correlations between Squat Jump Performance variables and non-scaled Isometric Mid-Thigh Pull data.

Variable	Isometric Mid-Thigh Pull				
	PF (N)	F50 (N)	F90 (N)	F200 (N)	IMP200 (N·s)
SJ0 JH (m)	0.43**	0.37**	0.40**	0.49**	0.44**
SJ0 PF (N)	0.51**	0.31**	0.28**	0.43**	0.35**
SJ0 PV ($m \cdot s^{-1}$)	0.42**	0.35**	0.37**	0.44**	0.41**
SJ0 PP (W)	0.56**	0.36**	0.35**	0.50**	0.42**
SJ0 F@PP (N)	0.50**	0.31**	0.28**	0.42**	0.35**
SJ0 V@PP ($m \cdot s^{-1}$)	0.43**	0.36**	0.38**	0.44**	0.41**
SJ20 JH (m)	0.55**	0.48**	0.51**	0.60**	0.56**
SJ20 PF (N)	0.48**	0.28**	0.25**	0.39**	0.32**
SJ20 PV ($m \cdot s^{-1}$)	0.50**	0.41**	0.43**	0.51**	0.47**
SJ20 PP (W)	0.56**	0.36**	0.34**	0.50**	0.41**
SJ20 F@PP (N)	0.48**	0.27**	0.24**	0.39**	0.31**
SJ20 V@PP ($m \cdot s^{-1}$)	0.50**	0.40**	0.42**	0.50**	0.46**

Note: PF: Peak force, F50: force at 50ms, F90: force at 90ms, F200: force at 200ms, IMP200: impulse from 0 to 200ms, JH: Jump height, PP: peak power, F@PP: force at peak power, PV: peak velocity, V@PP: velocity at peak power, **correlation is significant ($p<0.01$).

Table 4.4. Correlations between Squat Jump Performance variables and Isometric Mid-Thigh Pull data subtracted by body mass force.

Variable	Isometric Mid-Thigh Pull				
	PF (N)	F50 (N)	F90 (N)	F200 (N)	IMP200 (N·s)
SJ0 JH (m)	0.45**	0.36**	0.40**	0.51**	0.51**
SJ0 PF (N)	0.48**	$0.12^{\#}$	0.16*	0.37**	0.37**
SJ0 PV ($m\cdot s^{-1}$)	0.44**	0.35**	0.37**	0.45**	0.45**
SJ0 PP (W)	0.54**	0.20*	0.25**	0.46**	0.46**
SJ0 F@PP (N)	0.48**	$0.11^{\#}$	0.16	0.36**	0.36**
SJ0 V@PP ($m\cdot s^{-1}$)	0.44**	0.34**	0.37**	0.45**	0.45**
SJ20 JH (m)	0.55**	0.42**	0.47**	0.60**	0.60**
SJ20 PF (N)	0.46**	$0.09^{\#}$	0.13	0.34**	0.34**
SJ20 PV ($m\cdot s^{-1}$)	0.51**	0.36**	0.40**	0.51**	0.51**
SJ20 PP (W)	0.55**	0.20*	0.25**	0.46**	0.46**
SJ20 F@PP (N)	0.46**	$0.09^{\#}$	0.13	0.33**	0.33**
SJ20 V@PP ($m\cdot s^{-1}$)	0.50**	0.36**	0.39**	0.50**	0.50**

Note: PF: Peak force, F50: force at 50ms, F90: force at 90ms, F200: force at 200ms, IMP200: impulse from 0 to 200ms, JH: Jump height, PP: peak power, F@PP: force at peak power, PV: peak velocity, V@PP: velocity at peak power, *correlation is significant ($p<0.05$), **correlation is significant ($p<0.01$), $^{\#}$ different than non-scaled ($p<0.05$).

Table 4.5. Correlations between Squat Jump Performance variables and Isometric Mid-Thigh Pull divided by body mass (ratio scaling).

Variable	Isometric Mid-Thigh Pull				
	PF (N)	F50 (N)	F90 (N)	F200 (N)	IMP200 (N·s)
SJ0 JH (m)	0.40**	0.29**	0.34**	0.47**	0.40**
SJ0 PF (N)	0.25**$^{\#}$	-0.01$^{\#}$	0.02$^{\#}$	0.18*$^{\#}$	0.08$^{\#}$
SJ0 PV (m·s^{-1})	0.40**	0.28**	0.32**	0.41**	0.37**
SJ0 PP (W)	0.34**	0.08$^{\#}$	0.11$^{\#}$	0.29**$^{\#}$	0.19*$^{\#}$
SJ0 F@PP (N)	0.25**	-0.02$^{\#}$	0.01$^{\#}$	0.17*$^{\#}$	0.07$^{\#}$
SJ0 V@PP (m·s^{-1})	0.39**	0.27**	0.31**	0.40**	0.36**
SJ20 JH (m)	0.43**	0.31**$^{\#}$	0.38**	0.50**	0.44**
SJ20 PF (N)	0.24**$^{\#}$	-0.03$^{\#}$	-0.01$^{\#}$	0.15$^{\#}$	0.05$^{\#}$
SJ20 PV (m·s^{-1})	0.43**	0.28**	0.33**	0.43**	0.38**
SJ20 PP (W)	0.35**$^{\#}$	0.08$^{\#}$	0.12$^{\#}$	0.29**	0.19*$^{\#}$
SJ20 F@PP (N)	0.24**$^{\#}$	-0.04$^{\#}$	-0.01$^{\#}$	0.15$^{\#}$	0.05$^{\#}$
SJ20 V@PP (m·s^{-1})	0.42**	0.27**	0.32**	0.42**	0.37**

Note: PF: Peak force, F50: force at 50ms, F90: force at 90ms, F200: force at 200ms, IMP200: impulse from 0 to 200ms, JH: Jump height, PP: peak power, F@PP: force at peak power, PV: peak velocity, V@PP: velocity at peak power, *correlation is significant ($p<0.05$), **correlation is significant ($p<0.01$), $^{\#}$ different than non-scaled ($p<0.05$).

Table 4.6. Correlations between Squat Jump Performance variables and Isometric Mid-Thigh Pull allometric scaled.

Variable	Isometric Mid-Thigh Pull				
	PF (N)	F50 (N)	F90 (N)	F200 (N)	IMP200 (N·s)
SJ0 JH (m)	0.45**	0.35**	0.38**	0.50**	0.44**
SJ0 PF (N)	0.37**	0.12$^{\#}$	0.13	0.29**	0.20*
SJ0 PV (m·s^{-1})	0.44**	0.33**	0.36**	0.44**	0.41**
SJ0 PP (W)	0.46**	0.20*	0.21**	0.39**	0.29**
SJ0 F@PP (N)	0.37**	0.12$^{\#}$	0.12	0.28**	0.19*
SJ0 V@PP (m·s^{-1})	0.43**	0.33**	0.35**	0.43**	0.40**
SJ20 JH (m)	0.52**	0.41**	0.45**	0.57**	0.51**
SJ20 PF (N)	0.36**	0.10	0.09	0.26**	0.16*
SJ20 PV (m·s^{-1})	0.49**	0.36**	0.38**	0.49**	0.44**
SJ20 PP (W)	0.47**	0.20*	0.21**	0.39**	0.29**
SJ20 F@PP (N)	0.36**	0.09$^{\#}$	0.09	0.25**	0.16
SJ20 V@PP (m·s^{-1})	0.48**	0.35**	0.38**	0.48**	0.43**

Note: PF: Peak force, F50: force at 50ms, F90: force at 90ms, F200: force at 200ms, IMP200: impulse from 0 to 200ms, JH: Jump height, PP: peak power, F@PP: force at peak power, PV: peak velocity, V@PP: velocity at peak power, *correlation is significant ($p<0.05$), **correlation is significant ($p<0.01$), $^{\#}$ different than non-scaled ($p<0.05$).

Table 4.7. Correlations between Squat Jump Performance variables and Isometric Mid-Thigh Pull scaled to height.

Variable	Isometric Mid-Thigh Pull				
	PF (N)	F50 (N)	F90 (N)	F200 (N)	IMP200 (N·s)
SJ0 JH (m)	0.31**	0.21**	0.28**	0.40**	0.33**
SJ0 PF (N)	0.38**	0.14	0.14	0.30**	0.21*
SJ0 PV (m·s^{-1})	0.30**	0.20*	0.25**	0.35**	0.30**
SJ0 PP (W)	0.41**	0.16*$^{\#}$	0.18*	0.35**	0.25**
SJ0 F@PP (N)	0.37**	0.13	0.12	0.28**	0.19*
SJ0 V@PP (m·s^{-1})	0.31**	0.20*	0.26**	0.34**	0.30**
SJ20 JH (m)	0.40**$^{\#}$	0.29**$^{\#}$	0.36**	0.49**	0.41**$^{\#}$
SJ20 PF (N)	0.36**	0.11	0.10	0.26**	0.17*
SJ20 PV (m·s^{-1})	0.38**	0.25**	0.30**	0.41**	0.34**
SJ20 PP (W)	0.42**	0.16$^{\#}$	0.18*	0.36**	0.25**
SJ20 F@PP (N)	0.36**	0.11	0.10	0.26**	0.17*
SJ20 V@PP (m·s^{-1})	0.37**	0.24**	0.29**	0.40**	0.34**

Note: PF: Peak force, F50: force at 50ms, F90: force at 90ms, F200: force at 200ms, IMP200: impulse from 0 to 200ms, JH: Jump height, PP: peak power, F@PP: force at peak power, PV: peak velocity, V@PP: velocity at peak power, *correlation is significant ($p<0.05$), **correlation is significant ($p<0.01$), $^{\#}$ different than non-scaled ($p<0.05$).

Table 4.8. Correlations between Countermovement Jump Performance variables and Isometric Mid-Thigh Pull scaled to Sinclair coefficient.

Variable	Isometric Mid-Thigh Pull				
	PF (N)	F50 (N)	F90 (N)	F200 (N)	IMP200 (N·s)
SJ0 JH (m)	0.47**	0.39**	0.42**	0.53**	0.47**
SJ0 PF (N)	0.44**	0.21*	0.20*	0.36**	0.27**
SJ0 PV (m·s^{-1})	0.46**	0.38**	0.39**	0.47**	0.44**
SJ0 PP (W)	0.52**	0.29**	0.28**	0.45**	0.36**
SJ0 F@PP (N)	0.44**	0.20*	0.19*	0.34**	0.26**
SJ0 V@PP (m·s^{-1})	0.46**	0.37**	0.39**	0.46**	0.43**
SJ20 JH (m)	0.56**	0.48**	0.50**	0.61**	0.56**
SJ20 PF (N)	0.42**	0.18*	0.16*	0.32**	0.23**
SJ20 PV (m·s^{-1})	0.53**	0.42**	0.43**	0.52**	0.48**
SJ20 PP (W)	0.52**	0.29**	0.28**	0.45**	0.36**
SJ20 F@PP (N)	0.42**	0.17*	0.16	0.31**	0.23**
SJ20 V@PP (m·s^{-1})	0.52**	0.41**	0.42**	0.51**	0.47**

Note: PF: Peak force, F50: force at 50ms, F90: force at 90ms, F200: force at 200ms, IMP200: impulse from 0 to 200ms, JH: Jump height, PP: peak power, F@PP: force at peak power, PV: peak velocity, V@PP: velocity at peak power, *correlation is significant ($p<0.05$), **correlation is significant ($p<0.01$).

Discussion

As expected, statistically relevant correlations were found among IMTP force variables and SJ performances. All non-normalized values of the IMTP positively correlated with JH, PF, PV, PP, F@PP and V@PP for the SJ. These correlations were individually very similar or combined as a group (percentage values) higher than any other method of IMTP normalization data. A few higher non-statistical individual value correlations occurred when deducting the BM force (IMTP minus BM), in addition, the total number of correlations of this normalization presented just 33% of correlations higher than non-normalized, and thus these might not be the best representation for a better analysis. Another normalization that had similar individual correlations and it was the closest percentage of overall correlations (45% vs 55%) to non-normalized data was the Sinclair coefficient. Although not all values were higher, no correlation showed a great discrepancy. This normalization could be of interest especially because the IMTP Test was designed to mimic the second pull of the clean movement of weightlifting (9,10), and the Sinclair coefficient is derived from weightlifting competitions.

This study aimed to investigate and normalize different variables from the IMTP test, not just the absolute PF, because during the explosive act of jumping there is little time to apply forces, not being possible to achieve maximal forces. Thus, instantaneous forces during early phases of the pull (50, 90, 200ms) are important to jumping performance, especially when the athletes have little time to produce peak force and peak power (6,15). Thus, analyzing these phases were also an important part of this study showing positive correlations between these forces and SJ performance.

The majority of the normalizations had positive statistically significant correlations between force values and dynamic performance of jumps. The non-normalized data shows that the force values presented on this study have moderate (*r*=0.31) to large (*r*=0.60) correlations with SJ performance. This is an important finding for indicating that measurement of strength is an important variable to consider when monitoring athletes. Thus, strength would appear to be especially important when targeting dynamic performance and can be a guideline for aspects that might be important to train when aiming to increase performance on squat jumps.

Practical Applications

This study is important for strength coaches and sport scientist regarding the importance of strength and forces in the early phases of the force-time curve in the IMTP related to the dynamic performance of jumping. These relationships can serve as guides for specific types of strength training, such as basic and explosive resistance training, aiming at performance enhancement. Another application for the sport scientist to consider is that the most used methods of normalizing data did not result in better values for correlations between IMTP and SJ. Thus, when analyzing strength values no normalization may be needed for SJ performance.

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CHAPTER 5

NORMALIZATION OF ISOMETRIC MID-THIGH PULL FORCE VALUES AND COUNTERMOVEMENT JUMP PERFORMANCE

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Abstract

Vertical Jumps and strength tests are important tools used by many coaches to monitor and track athletes performance capacity. However, when comparing athletes with different body dimensions data normalization might be needed. This study aimed to analyze which method of data normalization for isometric mid-thigh pull (IMTP) force-time curve variables results in the best correlations to countermovement jump (CMJ) performance. Seventy-five male athletes and seventy-three females athletes (age 20.3±1.3y, height 176±10cm, and weight 75.4±13.1 kg) participated in this study. They performed a standardized warm-up, followed by a CMJ on a force-plate, and IMTP test. The IMTP force variables (peak force, force at 50ms, 90ms, 200ms and impulse from 0-200ms) data were normalized in the following methods: body mass (BM) ratio, force minus BM, allometric scale, Ford's height scale and with the Sinclair Coefficient scale. CMJ performance variables, such as jump height, PF, peak power, peak velocity, force at peak power, velocity at peak power, were correlated to non-normalized data and normalized data. Non-normalized correlation values presented overall higher grouped data (52% to 100% higher values) than other methods of normalization. Therefore, IMTP absolute variables have positive moderate to very large correlations to CMJ performance and there is no need to normalize data when correlating both variables.

Key-words: Testing, Strength, dynamic performance

Introduction

Testing of physical abilities has been widely popular and extensively used to assess muscle function, provide normative values for various groups of participants, evaluate the success of training, and evaluate the performance for sport- and work-related activities (1,15,31). One test that is commonly used in the literature to evaluate lower body power is the vertical jump (VJ) because it is a simple, quick, reliable minimum fatigue producing test of explosiveness (18). The VJ is highly correlated with other fundamental explosive movements performed in sports and with the maximum strength of the lower extremity (6,27,28).

Maximal strength tests are another worthwhile tool for monitoring athletes (23). The use of isometric tests examining peak force (PF) and force related variables are becoming extensively used by coaches to track their athletes' performance and monitor their training progress (3,4,7,11,12). One intervening factor that may influence strength levels is the athletes' size. Athletes with a larger body mass (BM) tend to have a greater amount of lean BM and this increase in lean BM often allows for a greater ability to express high levels of force (2,13,20,24,25,29). The impact of body size on force production makes it more difficult to compare athletes of differing sizes. Additionally, as athletes change their body mass during a season there may be difficulties in comparing the athlete progress over time. Another important consideration is that when strength is increased in conjunction with increased body mass improvements in performance in activities like vertical jumps may not be evident.

In order to be able to compare an athletes' performance during a season or between different athletes who have different body sizes (mass and height) several methods for normalizing results have been suggested. For example, ratio scaling, allometric scale, scaling by height, and the use of the Sinclair formula have all been suggests as methods for normalizing performance data (9,15,16,31).

While several methods of normalization have been proposed in the scientific literature, there is little data on how normalized performance data interrelate. Therefore, the aim of this study is to investigate several commonly used methods for normalizing IMTP force variables and determine their relationship to countermovement jump (CMJ) performance.

Methods

Experimental approach to the problem

This study was designed to analyze normalization methods for IMTP force variables in relation to maximal Vertical Jump (VJ) performance. Maximal isometric strength was selected as it provides an efficient measures of maximal strength in a variety of populations (12,21,22), and also it is possible to trace force at each moment of the force-time curve. The CMJ was selected because it is commonly used to assess VJ performance (27,33). A cross-sectional study with CMJ and IMTP were performed on the same day (fig. 1) aiming to see the relationship between force data and normalization between tests. The athletes had anthropometric values measured and then performed a standard warmup followed by CMJ tests and IMTP.

Figure 5.1. Study design.

Participants

Seventy-five male athletes and seventy-three females athletes (age 20.3±1.3y, height 176±10cm, and weight 75.4±13.1 kg) participated in this study. Subjects were D1 NCAA student athletes from several sports: baseball, soccer, basketball, track and field, tennis, softball, and volleyball. All participants were familiarized with the testing methods, they were informed of testing procedures previous to the start the testing. Testing was part of a regular athlete monitoring program performed just before the beginning of their competitive season and the athletes were already familiarized with testing that they had performed on previous years. The process was performed according to procedures outlined by the University Institutional Review Board.

Procedures

All athlete testing occurred on a single day of testing. This testing included: hydration, body composition (body weight, stature and body fat percentage), unloaded and loaded CMJs and IMTP testing. Upon arrival, athletes underwent a standardized warm-up of 25 jumping jacks, followed by 1x5 mid-thigh pulls with an unloaded bar (20 kg), and 3x5 with either 60 kg (for males) or 40 kg (for females) – previous unpublished data indicates that would be an average of 60 to 70% of power clean for this population

. Jumps were completed on force plates (91 cm x 45.5 cm Roughdeck HP, Rice Lake, WI) while data were sampled at 1,000 Hz.

Athletes completed general warm-up and specific trials warm-up before maximal effort CMJ at 50% and 75% of perceived maximal effort. In an effort to diminish any performance contributions coming from an arm swing, unloaded trials were completed while athletes held a PVC pipe just beneath the 7th cervical vertebrae behind the neck. The CMJ testing consisted of the athletes dropping to self-selected depths before jumping. Athletes completed two jumps for each load condition (0kg and 20kg) the average was used for data analysis. During loaded conditions, a 20 kg weightlifting bar was used. Loaded jump conditions were included to simulate fatiguing situations as well as to quantify athlete responses to an external load (17). Rest between jump trials was roughly one minute.

The IMTP was chosen for evaluation of strength because of its relationship to numerous sporting movements. This assessment was performed in a power rack that was custom-designed (Sorinex Inc., Irmo, SC) and incorporated two force plates (two 91 cm x 45.5 cm Roughdeck HP, Rice Lake, WI) that allow for limb to limb comparisons to be performed. All force time curve data was sampled a 1,000 Hz in order to ensure the Niquist Law was adhered to. Positioning in the IMTP was individually determined resulting in an upright trunk position and an average knee angle of 125±5º in accordance with previously published literature (12). Based upon the work of Haff et al. (1997) all IMTP assessments were performed with the use of standard weightlifting straps in conjunction with athletic tape in order to ensure that grip on the bar was maintained during the entire pulling motion. Prior to the initiation of each maximal effort trial, specific warm-up trials were performed at 50% and 75% of perceived effort. During the maximal effort trials each athlete was instructed to “pull as fast and as hard as possible” in in order to ensure that a high rate of force development (RFD) and maximum force were achieved (Haff et al. 1997). Two trials were completed and data were averaged for analysis. A countermovement greater than 200 N at the initiation of the IMTP would render the trial unsuccessful, requiring an additional trial. An additional trial was also required if the athlete had a difference higher than 250 N on peak force between pulls (17). Rest between IMTP trials was greater than one minute.

Analog data from the force plate were amplified and low-pass filtered at 16 Hz (Transducer Techniques, Temecula, CA). Force-time curves were digitally filtered using a 4th order Butterworth low-pass filter at 40 Hz and analyzed using a custom LabView program (LabView 2010, National Instruments).

Analysis

The data from IMTP force time curve analysis included the PF, Force at 50ms (F50), Force at 90ms (F90), Force at 200ms (F200) and Impulse from 0-200ms (IMP200). All force time curve data were analyzed with the use of six different normalization procedures, including: a) non-scaled (raw force values), b) force values minus body mass in Newtons (N), c) Body Mass ratio scaling - scaled to body mass (F divided by BM), d) allometric scale ($F/BM^{2/3}$), e) Ford’s height scale ($F/Height^{2.16}$), d) Sinclair value scale (force times Sinclair coefficients for the Olympiad 2013-2016).

Vertical jump force time curve analyses were used to determine the Jump Height (JH), jumping PF, peak velocity (PV), peak power (PP), force at peak power (F@PP) and velocity at peak power (V@PP). According to previous research, the performance of rapid body movements (jumps included) is not likely to require normalization for body size (16), and that is supported by Markovic and Jaric (2007) indicating that vertical jumps can be considered as a body size-independent index of muscle power (19).

All IMTP data were correlated (Pearson's Product Moment correlation) with the performance measured collected during the CMJ. The correlations were categorized, according to Hopkins (2002), as 0.0-0.1 trivial, 0.1-0.3 small, 0.3-0.5 moderate, 0.5-0.7 large, 0.7-0.9 very large, and 0.9-1.0 nearly perfect. A comparison of correlations, Fisher's *r* to *Z* transformation, was used to check for any statistical differences among correlations (30). The total number of correlations for each method was used to check if any method had a higher percent of higher correlations than the non-normalized method. Prior to statistical analysis, data were screened for within session test-retest reliability, outliers and normality. Reliability was assessed using ICCs and CV, the 90% of CI was reported.

Results

Values of JH, PF, PV, PP, F@PP and V@PP, for the two trials of CMJ, were considered adequately reliable for analysis (ICC ranging from 0.88-0.99, CV between trials 3.1-4.6% and group CV from 10.3-27.2%). The IMTP values of PF, F50, F90, F200 and IMP200 without normalization and normalized were also considered reliable – ICC 0.90-0.99, CV between trials 3.1-10.0% and group CV 21.5-31.2 %, the data for Force values minus the BM which had higher group CV 29.8-55.8%. There was no statistical differences between the above cited variables between the two trials performed, the high CV values are expected and they are due to having a large non-homogenous group.

Descriptive data for the CMJ and pulls are shown in tables 1 and 2. Correlations between each IMTP values – non-scaled, values minus BM, scaled to BM, allometric scale, Height scale, and Sinclair scale, to all CMJ variables presented, in general, higher correlation values for the non-normalized method (tables 3 to 8). The non-normalized method also presented overall higher correlations values, when grouped 75% of all correlations from non-normalized were higher than the data subtracting the body mass force, 100% than the normalizing by dividing per BM, 93% higher than the allometric scale, 100% higher than Ford's height and 52% higher than the Sinclair coefficient scale.

Table 5.1. Descriptive data from Countermovement Jumps.

		JH (m)	PF (N)	PV ($m \cdot s^{-1}$)	PP (W)	F@PP (N)	V@PP ($m \cdot s^{-1}$)
CMJ 0Kg	Mean	0.32	1783.3	2.67	3822.2	1564.5	2.42
	SD (±)	0.07	378.6	0.29	1030.7	321.6	0.25
	CI	0.31 - 0.33	1731.8 - 1834.8	2.63 - 2.71	3682.0 - 3962.4	1520.7 - 1608.3	2.38 - 2.45
CMJ 20Kg	Mean	0.24	1907.0	2.36	3785.5	1733.8	2.15
	SD (±)	0.06	361.9	0.28	1031.7	318.0	0.25
	CI	0.23 - 0.25	1857.7 - 1956.2	2.32 - 2.40	3645.1 - 3925.9	1690.5 - 1777.1	2.12 - 2.18

Note: CMJ: Countermovement jump, CI: 90%Confidence interval, JH: Jump height, PP: peak power, F@PP: force at peak power, PV: peak velocity, V@PP: velocity at peak power.

Table 5.2. Descriptive data from the isometric mid-thigh pulls, non-normalized and normalized methods.

		PF (N)	F50 (N)	F90 (N)	F200 (N)	IMP 200 (N·s)
Non-normalized	Mean	3606.4	1175.3	1507.1	2349.3	320.2
	SD (±)	943.6	309.5	471.0	703.0	93.3
	CI	3478.0 – 3734.7	1133.2 – 1217.4	1443.0 – 1571.2	2253.6 – 2444.9	307.5 – 332.9
Subtracted BM	Mean	2867.1	436.0	767.8	1609.9	322.0
	SD (±)	855.5	243.3	405.4	628.5	125.7
	CI	2750.7 – 2983.5	402.9 – 469.1	712.6 – 822.9	1524.4 – 1695.4	304.9 – 339.1
Divided by BM	Mean	47.7	15.6	19.9	31.0	4.2
	SD (±)	8.6	3.1	4.8	6.9	0.9
	CI	46.5 – 48.8	15.2 – 16.0	19.2 – 20.6	30.0 – 31.9	4.0 – 4.3
Allometric	Mean	201.0	65.6	83.9	130.8	17.8
	SD (±)	39.3	13.6	21.5	31.1	4.1
	CI	195.6 – 206.3	63.7 – 67.4	81.0 – 86.8	126.6 – 135.0	17.2 – 18.4
Ford's Height	Mean	1058.9	346.3	443.0	688.9	94.1
	SD (±)	222.1	79.8	122.2	168.9	23.3
	CI	1028.7 – 1089.1	335.4 – 357.2	426.4 – 459.6	665.9 – 711.9	90.9 – 97.3
Sinclair Coefficient	Mean	4480.6	1461.5	1871.9	2917.6	397.7
	SD (±)	1004.1	337.1	524.1	769.5	102.3
	CI	4344.0 – 4617.2	1415.6 – 1507.4	1800.6 – 1943.2	2812.9 – 3022.3	383.8 – 411.6

Note: CI: 90%Confidence Interval, Peak force, F50: force at 50ms, F90: force at 90ms, F200: force at 200ms, IMP200: impulse from 0 to 200ms.

Table 5.3. Correlations between Countermovement Jump Performance variables and non-scaled Isometric Mid-Thigh Pull data.

Variable	Isometric Mid-Thigh Pull				
	PF (N)	F50 (N)	F90 (N)	F200 (N)	IMP200 (N·s)
CMJ0 JH (m)	0.43**	0.33**	0.35**	0.46**	0.40**
CMJ0 PF (N)	0.71**	0.62**	0.59**	0.66**	0.64**
CMJ0 PV (m·s^{-1})	0.70**	0.57**	0.55**	0.65**	0.61**
CMJ0 PP (W)	0.71**	0.61**	0.57**	0.64**	0.62**
CMJ0 F@PP (N)	0.42**	0.32**	0.33**	0.43**	0.38**
CMJ0 V@PP (m·s^{-1})	0.41**	0.31**	0.31**	0.42**	0.37**
CMJ20 JH (M)	0.51**	0.44**	0.46**	0.57**	0.51**
CMJ20 PF (N)	0.72**	0.65**	0.60**	0.67**	0.65**
CMJ20 PV (m·s^{-1})	0.70**	0.58**	0.56**	0.65**	0.62**
CMJ20 PP (N)	0.71**	0.61**	0.57**	0.64**	0.62**
CMJ20 F@PP	0.53**	0.43**	0.43**	0.53**	0.48**
CMJ20 (N) V@PP (m·s^{-1})	0.52**	0.42**	0.42**	0.52**	0.47**

Note: PF: Peak force, F50: force at 50ms, F90: force at 90ms, F200: force at 200ms, IMP200: impulse from 0 to 200ms, JH: Jump height, PP: peak power, F@PP: force at peak power, PV: peak velocity, V@PP: velocity at peak power, **correlation is significant ($p<0.01$).

Table 5.4. Correlations between Countermovement Jump Performance variables and Isometric Mid-Thigh Pull data subtracted by body mass force.

Variable	Isometric Mid-Thigh Pull				
	PF (N)	F50 (N)	F90 (N)	F200 (N)	IMP200 (N·s)
CMJ0 JH (m)	0.45**	0.30**	0.33**	0.47**	0.47**
CMJ0 PF (N)	0.66**	0.38**$^{\#}$	0.44**$^{\#}$	0.58**	0.58**
CMJ0 PV ($m \cdot s^{-1}$)	0.66**	0.37**$^{\#}$	0.43**	0.59**	0.59**
CMJ0 PP (W)	0.66**	0.34**$^{\#}$	0.41**$^{\#}$	0.55**	0.55**
CMJ0 F@PP (N)	0.43**	0.29**	0.31**	0.44**	0.44**
CMJ0 V@PP ($m \cdot s^{-1}$)	0.42**	0.28**	0.30**	0.43**	0.43**
CMJ20 JH (M)	0.52**	0.39**	0.43**	0.57**	0.57**
CMJ20 PF (N)	0.68**	0.41**$^{\#}$	0.45**$^{\#}$	0.59**	0.59**
CMJ20 PV ($m \cdot s^{-1}$)	0.67**	0.39**$^{\#}$	0.44**	0.59**	0.59**
CMJ20 PP (N)	0.66**	0.35**$^{\#}$	0.41**$^{\#}$	0.55**	0.55**
CMJ20 F@PP	0.53**	0.37**	0.40**	0.53**	0.53**
CMJ20 (N) V@PP ($m \cdot s^{-1}$)	0.52**	0.36**	0.38**	0.52**	0.52**

Note: PF: Peak force, F50: force at 50ms, F90: force at 90ms, F200: force at 200ms, IMP200:: impulse from 0 to 200ms, JH: Jump height, PP: peak power, F@PP: force at peak power, PV: peak velocity, V@PP: velocity at peak power, **correlation is significant ($p<0.01$), $^{\#}$ different than non-scaled ($p<0.05$).

Table 5.5. Correlations between Countermovement Jump Performance variables and Isometric Mid-Thigh Pull divided by body mass (ratio scaling).

Variable	Isometric Mid-Thigh Pull				
	PF (N)	F50 (N)	F90 (N)	F200 (N)	IMP200 (N·s)
CMJ0 JH (m)	0.40**	0.23**	0.27**	0.41**	0.33**
CMJ0 PF (N)	0.31**$^{\#}$	0.17*$^{\#}$	0.22**$^{\#}$	0.31**$^{\#}$	0.26**$^{\#}$
CMJ0 PV (m·s^{-1})	0.36**$^{\#}$	0.17*$^{\#}$	0.23**$^{\#}$	0.34**$^{\#}$	0.28**$^{\#}$
CMJ0 PP (W)	0.27**$^{\#}$	0.11$^{\#}$	0.17*$^{\#}$	0.25**$^{\#}$	0.20*$^{\#}$
CMJ0 F@PP (N)	0.39**	0.24**	0.26**	0.39**	0.32**
CMJ0 V@PP (m·s^{-1})	0.38**	0.22**	0.25**	0.38**	0.31**
CMJ20 JH (M)	0.42**	0.30**	0.35**	0.48**	0.41**
CMJ20 PF (N)	0.32**$^{\#}$	0.19*$^{\#}$	0.23**$^{\#}$	0.31**$^{\#}$	0.27**$^{\#}$
CMJ20 PV (m·s^{-1})	0.38**$^{\#}$	0.20*$^{\#}$	0.25**$^{\#}$	0.36**$^{\#}$	0.30**$^{\#}$
CMJ20 PP (N)	0.29**$^{\#}$	0.13$^{\#}$	0.18*$^{\#}$	0.25**$^{\#}$	0.21**$^{\#}$
CMJ20 F@PP	0.43**	0.27**	0.30**	0.43**	0.36**
CMJ20 (N) V@PP (m·s^{-1})	0.43**	0.27**	0.29**	0.42**	0.35**

Note: PF: Peak force, F50: force at 50ms, F90: force at 90ms, F200: force at 200ms, IMP200: impulse from 0 to 200ms, JH: Jump height, PP: peak power, F@PP: force at peak power, PV: peak velocity, V@PP: velocity at peak power, *correlation is significant ($p<0.05$), **correlation is significant ($p<0.01$), $^{\#}$ different than non-scaled ($p<0.05$).

Table 5.6. Correlations between Countermovement Jump Performance variables and Isometric Mid-Thigh Pull allometric scaled.

Variable	Isometric Mid-Thigh Pull				
	PF (N)	F50 (N)	F90 (N)	F200 (N)	IMP200 (N·s)
CMJ0 JH (m)	0.44**	0.29**	0.32**	0.45**	0.38**
CMJ0 PF (N)	0.50**$^{\#}$	0.37**$^{\#}$	0.38**$^{\#}$	0.47**$^{\#}$	0.43**$^{\#}$
CMJ0 PV (m·s^{-1})	0.53**	0.35**$^{\#}$	0.37**$^{\#}$	0.48**$^{\#}$	0.43**$^{\#}$
CMJ0 PP (W)	0.48**$^{\#}$	0.33**$^{\#}$	0.34**$^{\#}$	0.42**$^{\#}$	0.38**$^{\#}$
CMJ0 F@PP (N)	0.43**	0.29**	0.30**	0.43**	0.36**
CMJ0 V@PP (m·s^{-1})	0.42**	0.27**	0.29**	0.42**	0.35**
CMJ20 JH (M)	0.49**	0.38**	0.41**	0.54**	0.47**
CMJ20 PF (N)	0.52**$^{\#}$	0.39**$^{\#}$	0.39**$^{\#}$	0.47**$^{\#}$	0.44**$^{\#}$
CMJ20 PV (m·s^{-1})	0.54**$^{\#}$	0.37**$^{\#}$	0.38**$^{\#}$	0.49**$^{\#}$	0.44**$^{\#}$
CMJ20 PP (N)	0.49**$^{\#}$	0.34**$^{\#}$	0.34**$^{\#}$	0.42**	0.39**$^{\#}$
CMJ20 F@PP	0.50**	0.36**	0.37**	0.49**	0.43**
CMJ20 (N) V@PP (m·s^{-1})	0.50**	0.35**	0.36**	0.48**	0.42**

Note: PF: Peak force, F50: force at 50ms, F90: force at 90ms, F200: force at 200ms, IMP200: impulse from 0 to 200ms, JH: Jump height, PP: peak power, F@PP: force at peak power, PV: peak velocity, V@PP: velocity at peak power, **correlation is significant ($p<0.01$), $^{\#}$ different than non-scaled ($p<0.05$).

Table 5.7. Correlations between Countermovement Jump Performance variables and Isometric Mid-Thigh Pull scaled to height.

Variable	Isometric Mid-Thigh Pull				
	PF	F50	F90	F200	IMP200
CMJ0 JH (m)	0.30**	0.15	0.21*	0.35**	0.26**
CMJ0 PF (N)	0.52**#	0.38**#	0.39**#	0.49**#	0.44**#
CMJ0 PV (m·s^{-1})	0.49**#	0.31**#	0.34**#	0.46**#	0.39**#
CMJ0 PP (W)	0.49**#	0.33**#	0.35**#	0.44**#	0.39**#
CMJ0 F@PP (N)	0.31**	0.18*	0.21**	0.35**	0.27**
CMJ0 V@PP (m·s^{-1})	0.29**	0.15	0.19*	0.33**	0.25**
CMJ20 JH (M)	0.36**#	0.25**#	0.31**	0.44**	0.36**
CMJ20 PF (N)	0.54**#	0.41**#	0.40**#	0.49**#	0.46**#
CMJ20 PV (m·s^{-1})	0.49**#	0.33**#	0.35**#	0.47**#	0.40**#
CMJ20 PP (N)	0.51**#	0.35**#	0.35**#	0.44**	0.40**#
CMJ20 F@PP	0.38**	0.24**#	0.28**	0.41**	0.33**
CMJ20 (N) V@PP (m·s^{-1})	0.37**	0.22**#	0.26**	0.39**	0.31**

Note: PF: Peak force, F50: force at 50ms, F90: force at 90ms, F200: force at 200ms, IMP200: impulse from 0 to 200ms, JH: Jump height, PP: peak power, F@PP: force at peak power, PV: peak velocity, V@PP: velocity at peak power, *correlation is significant (p<0.05), **correlation is significant (p<0.01), # different than non-scaled (p<0.05).

Table 5.8. Correlations between Countermovement Jump Performance variables and Isometric Mid-Thigh Pull scaled to Sinclair coefficient.

Variable	Isometric Mid-Thigh Pull				
	PF (N)	F50 (N)	F90 (N)	F200 (N)	IMP200 (N·s)
CMJ0 JH (m)	0.48**	0.35**	0.36**	0.49**	0.42**
CMJ0 PF (N)	0.60**	0.49**	0.48**	0.56**	0.53**
CMJ0 PV (m·s^{-1})	0.62**	0.47**	0.47**	0.57**	0.53**
CMJ0 PP (W)	0.59**	0.46**$^{\#}$	0.45**	0.53**	0.50**
CMJ0 F@PP (N)	0.46**	0.34**	0.34**	0.46**	0.40**
CMJ0 V@PP (m·s^{-1})	0.45**	0.33**	0.33**	0.45**	0.39**
CMJ20 JH (M)	0.54**	0.45**	0.46**	0.58**	0.52**
CMJ20 PF (N)	0.62**	0.52**$^{\#}$	0.49**	0.57**	0.54**
CMJ20 PV (m·s^{-1})	0.63**	0.49**	0.48**	0.58**	0.54**
CMJ20 PP (N)	0.60**$^{\#}$	0.47**$^{\#}$	0.45**	0.53**	0.50**
CMJ20 F@PP	0.55**	0.43**	0.43**	0.54**	0.49**
CMJ20 (N) V@PP (m·s^{-1})	0.55**	0.43**	0.42**	0.53**	0.48**

Note: PF: Peak force, F50: force at 50ms, F90: force at 90ms, F200: force at 200ms, IMP200: impulse from 0 to 200ms, JH: Jump height, PP: peak power, F@PP: force at peak power, PV: peak velocity, V@PP: velocity at peak power, **correlation is significant ($p<0.01$), $^{\#}$ different than non-scaled ($p<0.05$).

Discussion

These results indicates the importance of strength values, peak force and instantaneous forces, particularly at the beginning of the IMTP force-time curve, which have positive correlations to vertical jump performance ranging from moderate (*r*=0.31) to very large (*r*=0.72). In addition, the non-normalized data presented generally a higher number of high correlations than the normalized values, ranging from 52% to 100% of the total correlations compared.

The normalization by Sinclair Coefficient showed slightly higher correlation values than some of the non-normalized data; it was not the majority of the overall correlations (43% vs 52%), thus probably not leading to the best way of normalizing IMTP data for VJ performance. However, it is an interesting way of analysis because it is a non-linear normalization, and shows that being heavier might lead to being stronger and producing a better performance on the CMJ. Another point to consider is that the Sinclair Coefficient is a value derived from weightlifting results, and the IMTP was in part created with one of the intentions to mimic the second pull of the weightlifting movements, power position (10,12).

Normalizing IMTP force data by the simple BM ratio showed at their best some positive moderate effect correlations with CMJ. Comfort & Pearson (2014) and Nedeljkovic et al., (2009) report similar findings showing that simple BM ratio for strength tests does not seem to be the best way of normalizing strength and power tests (1RM) aiming dynamic performance (sprints). These findings may partially be explained by differences between the distribution of muscle mass to body fat ratios (5). Additionally, increases in BM ratio distribution between muscle and fat mass is not consistent. Therefore, the BM ratio does not seem to be a good way of normalization the IMTP when attempting to correlate it to CMJ performance. The use of different normalization procedures might partially explain the different findings found in the scientific literature in regard to relationships between the IMTP and performance. For example, Thomas et al., (2015), used BM ratio and did not finding significant correlations between IMTP and impulse. Conversely, Kraska et al. (2009) and Stone et al. (2005) both found significant correlations between IMTP and impulse when using allometric scaling for data normalization.

Nedeljkovic et al., (2009) also indicated that an allometric scale for normalization could be beneficial. However, it is important to note that the exponent of 0.67(2/3 of BM) might be inaccurate due to weight and inertia of the limbs, which are producing external work during the test. Our findings showed positive and mostly moderate correlations, however normalizing these data for VJ does not seem to be a better approach than non-normalized data. Perhaps adjusting the allometric values would yield better results. However, Nedeljkovic et al., (2009) suggested the use of an allometric scale with higher allometric exponents would result in overvaluing the BM allometric scale value and result in a scaling impact on performance being artificially inflated.

Nedeljkovic et al., (2009) also used subject’s height to normalize data, but like our findings, results of their study indicate that this method is not the best way of normalizing data. In the present study, the normalization of data by height with the methods of Ford et al., (2000) and Stone et al., (2005), both of which used a specific population of weightlifters in which the groups were heterogeneous (all weight classes and both sexes). Although we also had a heterogeneous population in this study, the correlation values were lower than non-normalized data and this might have occurred because height differences between subjects were not large enough.

There are several limitations regarding body composition (size, gender, fat, muscle mass, muscle cross-sectional area, limbs size) (16), which makes it difficult to use a single normalization test. Therefore, studying the effects of body size on performance produces in general, a weak to moderate effect (15,18,26); it is generally believed that the problem originates from a relatively narrow scale of human body sizes (16,26). The different IMTP normalized values presented on this study did not show consistently superior correlations than non-normalized values when correlating with dynamic VJ performance. Therefore, using non-normalized values for IMTP force values analyses is simpler and might be more, or as effective as any of the most used normalizations when targeting VJ performance.

Practical Applications

This study shows the relationships of strength especially in the early phases of the force-time curve in the IMTP related to the dynamic performance of jumping. This finding could lead strength coaches to use appropriate basic, explosive strength and power exercises when targeting improved performances for jumping. Data normalization for IMTP and CMJ does not show better correlations values than the absolute numbers, thus no normalization is necessarily needed for IMTP when correlating it to dynamic CMJ performance, which agrees with previous studies correlating IMTP and weightlifting performance (4).

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CHAPTER 6

SUMMARY AND FUTURE RESEARCH

The purpose of this dissertation was to evaluate differences between distinct position on the IMTP and if pulling position results in the correlations of the IMTP to dynamic performance of jumping. In addition, this dissertation also aimed to investigate if there is a normalization method for the data collected with the IMTP that could impact the correlate of the test with the SJ and CMJ. Particularly, the first study compared force variables of two different pulling positions (slightly bent and upright trunk position) on the IMTP. The upright position showed statistically significant higher values for PF, F50, F90, F200, RFD200 and IMP200 than bent position and greater reliability. However, when correlating those values to VJ performance, there was no statistical difference between positions correlations to JH, dynamic PF, PP, PV, F@PP and V@PP of SJ and CMJ. The second and third studies had similar goals to evaluate if there is a normalization method that better fits the IMTP force values when correlating to VJ performance. The second article revealed that the non-normalized data showed moderate to large effects when correlating IMTP force variables to SJ performance, neither BM ratio, allometric scale, Ford's height scale or Sinclair Coefficient scale repeatedly showed higher value correlations than the non-normalized values. The third study correlated the IMTP values and its normalized values just described to CMJ, the results show higher correlations to non-normalized IMTP values and correlations ranging from moderate to very large. Therefore, there is no need to have data normalization when correlating IMTP force values and VJ performance.

Practical Applications

Strength and explosive dynamic performance tests are being commonly used in research and testing for athletic population. The IMTP has become a popular test in the scientific field, for higher values in the early phase of force-time curve and PF, the suggested position for this test is upright torso (145° hip angle) and knees bent at 125°. In addition, there is no need to normalize the IMTP data when aiming to correlate to VJ, both SJ and CMJ. Practical implications from this dissertation to the sport suggest that the stronger the athlete, especially at early phases on the IMTP force-time curve, greater the chances of performing better at VJ tests.

Future Research

The first study showed higher force values and greater reliability for the upright position than the bent position, but these changes did not present differences among correlations to vertical jump performance. However, that was a cross-sectional study, a longitudinal study with strength training should increase force values and change dynamic performance, so future researches can aim to analyze these changes and check if, over time and training, the changes that might occur in the relationships between ITMP positions and VJ performance. The studies 2 and 3 showed that the most common data normalizations for body size did not present consistently better results than the values non-normalized, thus future researches aiming correlations between IMTP and VJ do not need normalization for IMTP force values.

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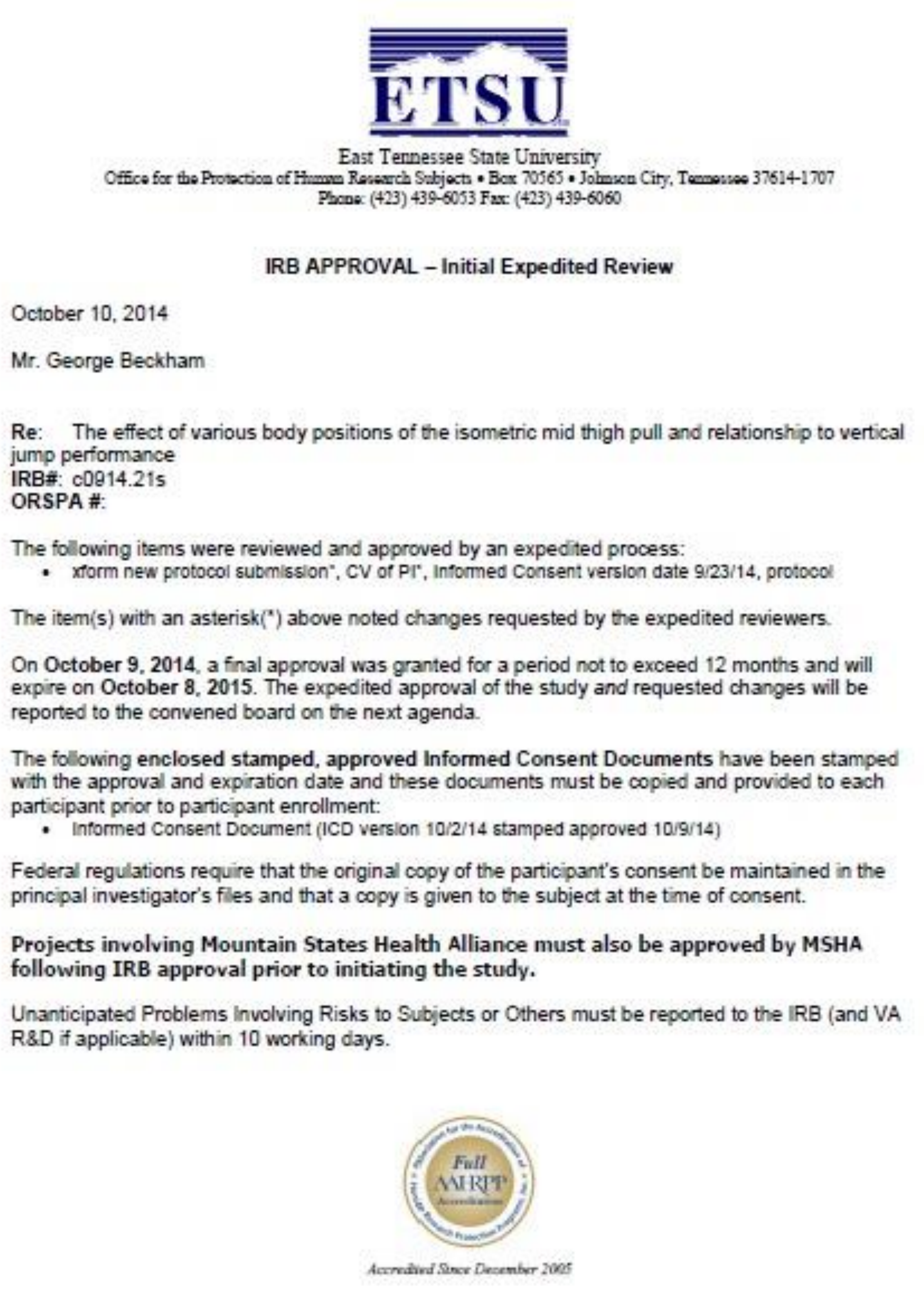
APPENDICES

Appendix A: Institutional Review Board Approval



ETSU
East Tennessee State University
Office for the Protection of Human Research Subjects • Box 70565 • Johnson City, Tennessee 37614-1707
Phone: (423) 439-6053 Fax: (423) 439-6060

IRB APPROVAL – Initial Expedited Review

October 10, 2014

Mr. George Beckham

Re: The effect of various body positions of the isometric mid thigh pull and relationship to vertical jump performance
IRB#: c0914.21s
ORSPA #:

The following items were reviewed and approved by an expedited process:

- xform new protocol submission*, CV of PI*, Informed Consent version date 9/23/14, protocol

The item(s) with an asterisk(*) above noted changes requested by the expedited reviewers.

On **October 9, 2014**, a final approval was granted for a period not to exceed 12 months and will expire on **October 8, 2015**. The expedited approval of the study *and* requested changes will be reported to the convened board on the next agenda.

The following **enclosed stamped, approved Informed Consent Documents** have been stamped with the approval and expiration date and these documents must be copied and provided to each participant prior to participant enrollment:

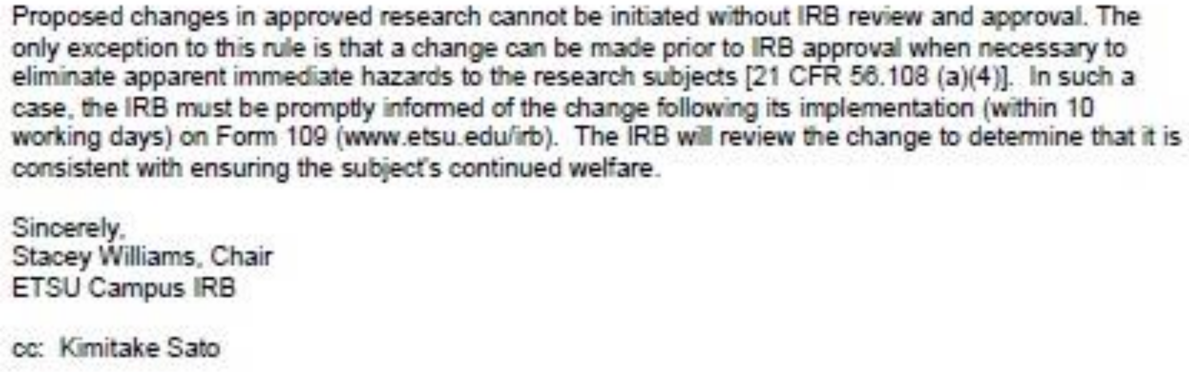
- Informed Consent Document (ICD version 10/2/14 stamped approved 10/9/14)

Federal regulations require that the original copy of the participant's consent be maintained in the principal investigator's files and that a copy is given to the subject at the time of consent.

Projects involving Mountain States Health Alliance must also be approved by MSHA following IRB approval prior to initiating the study.

Unanticipated Problems Involving Risks to Subjects or Others must be reported to the IRB (and VA R&D if applicable) within 10 working days.

Accredited Since December 2005



Proposed changes in approved research cannot be initiated without IRB review and approval. The only exception to this rule is that a change can be made prior to IRB approval when necessary to eliminate apparent immediate hazards to the research subjects [21 CFR 56.108 (a)(4)]. In such a case, the IRB must be promptly informed of the change following its implementation (within 10 working days) on Form 109 (www.etsu.edu/irb). The IRB will review the change to determine that it is consistent with ensuring the subject's continued welfare.

Sincerely,
Stacey Williams, Chair
ETSU Campus IRB

cc: Kimitake Sato

Appendix B: Informed Consent Document

Principle Investigator: George K. Beckham

Title of Project: The effect of various body positions on performance of the isometric mid-thigh pull

SUBJECT CONSENT FORM FOR PARTICIPATION OF HUMAN SUBJECTS IN RESEARCH

Project Title:	**The effect of various body positions of the isometric mid thigh pull and relationship to vertical jump performance**
Primary Investigator:	George Beckham, MA, Department of Exercise and Sport Sciences gkbeckham@gmail.com
Faculty Advisor:	Kimitake Sato, PhD, Department of Exercise and Sport Sciences Satok1@etsu.edu
Co-investigators:	Hugo Santana, MS, Department of Exercise and Sport Sciences santana@goldmail.etsu.edu Michael Stone, PhD, Department of Exercise and Sport Sciences stonemh@etsu.edu Satoshi Mizuguchi, PhD, Department of Exercise and Sport Sciences mizuguchi@etsu.edu
Phone:	423-439-4655 (Sport Science Lab; Minidome E113)

INTRODUCTION:
You are being asked to participate in a research project. This informed consent will explain what your participation will entail as a subject. Please read this consent form carefully and decide if you wish to participate in this study.

PURPOSES OF THE STUDY:
The purposes of this study are:

- To determine the effect of learning and familiarization on force production during the isometric mid-thigh pull test.
- To determine the force production differences that may exist with different body positions in the isometric mid-thigh pull.
- To determine the effect that training background may have on the above two purposes.
- To examine the effect of changing body position in the isometric pull on EMG activity of various muscles.
- To determine the relationship of different isometric mid-thigh pull positions to countermovement and static jumps.

DURATION:
Participation in this study would involve attending five total sessions. Each session will last approximately 90 minutes.

PROCEDURES:
You will be asked to participate in five sessions, the specifics of which are listed below. Each session will be separated by 72-96 hours.

- Session 1: Investigators will take basic anthropometric measurements (height and weight), and you will be measured and evaluated for the proper pulling positions used in the familiarization

APPROVED
By the ETSU IRB
OCT 09 2014
By ____ Chair/IRB Coordinator

DOCUMENT VERSION EXPIRES
OCT 08 2015
ETSU IRB

October 2, 2014 Page 1 Subject Initials: _______

process, and in final testing. After measurements have been completed, you will complete two isometric pulls at 50% maximum effort, two isometric pulls at 75% maximum effort, and one isometric pull at 100% effort for 2 seconds in two separate body positions.

- Session 2: You will perform two isometric pulls at 50% effort, 75% effort, and 100% effort in both body positions for 4-5 seconds each.
- Session 3: You will perform a total of eight vertical jumps: four countermovement and four static jumps. You will perform a jump at 50% (1 jump), 75% (1 jump) and 100% effort (2 jumps) with each type of vertical jump. You will repeat the isometric pull familiarization protocol of the first session.
- Session 4: You will repeat the isometric pull familiarization protocol of the first session.
- Session 5: You will perform a testing session identical to session two.

POSSIBLE RISKS/DISCOMFORT:

There is no more than minimal risk in participating. You will experience physiological responses normal to physical exertion (sweating, increased heart rate, increased respiration rate). You may also experience some muscle and/or joint soreness as a result of the testing protocol.

POSSIBLE BENEFITS/COMPENSATION:

There is no compensation nor benefits from your participation. However, as an indirect benefit, you get the opportunity to participate in important and innovative strength and conditioning research.

CONFIDENTIALITY:

Measures will be taken to ensure that your data and identity are kept confidential. Data sheets in hard copy will be kept in the locked office of the primary investigator (MiniDome E110), and digital copies of data sheets and compiled data will be stored on a password protected computer kept in the locked office of the primary investigator. Your rights and privacy will be maintained. The following persons/bodies will have access to study records: the Secretary of the Department of Health and Human Services, the ETSU Institutional Review Board, and personnel particular to this research project within the Department of Exercise and Sport Sciences.

VIDEO RECORDING AND STILL IMAGES:

Your participation in this project will be documented by video and still images. This documentation is necessary for measurement of joint angles during the isometric pulls. Furthermore, videos and/or still images may be used for demonstration or presentation of the study findings in presentations and research manuscripts. Your identity will remain confidential.

VOLUNTARY PARTICIPATION:

There are no penalties for not participating in this study. Your course grades will not be affected by your decision whether or not to participate. You are free to withdraw from the study at any time without explanation, regardless of prior participation. Your withdrawal will be respected, and will not result in any loss of benefits to which you are otherwise entitled. Should you experience an injury during the study period, you will be excluded as a subject.

CONTACT FOR QUESTIONS:

You may contact any of the following persons for questions, problems, or medical issues related to this study at any time. You may contact George Beckham at 423-218-9561, Hugo Santana at 423-218-7826,

Principle Investigator: George K. Beckham

Title of Project: The effect of various body positions on performance of the isometric mid-thigh pull

Dr. Kimitake Sato at 423-439-5138, or Dr. Michael Stone at 423-439-5796. If you have any questions about your rights as a research subject, you may contact the Chairman of the Institutional Review Board at 423-439-6054 or the Institutional Review Board Coordinator at 423-439-6055 or 423-439-6002. If you have any questions or concerns about the research and want to talk to someone independent of the research team or you can't reach the study staff, you may call an IRB coordinator at 423-439-6055 or 423-439-6002.

Having read the above and had the opportunity to ask any questions, please indicate with your signature below and with your initials on the previous pages that you have read and consent to participate in this research study, and that you are at least 18 years of age. You will receive a copy of this informed consent form after signing the form.

____
Participant's Name (please print) Date

____
Participant's Signature Date

____
Primary Investigator's Signature Date

APPROVED
By the ETSU/IRB
OCT 09 2014
By____________
Chair/IRB Coordinator

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ETSU IRB

VITA

HUGO ALEXANDRE DE PAULA SANTANA

Education:

B.S. Physical Education. Universidade Federal de Uberlândia – MG, Brazil, 2007.

M.S. Physical Education, Physical Activity and Health. Universidade Católica de Brasília – DF, Brazil, 2010.

Ph.D. Sport Physiology & Performance. East Tennessee State University, Johnson City, TN, 2016.

Experience:

Sport Scientist Intern, Sporting Kansas City (Major League Soccer), 2015.

Sport Scientist/Strength and Conditioning Coach, East Tennessee State Men’s Tennis, 2012-2015.

Assistant Sport Scientist/Strength and Conditioning Coach, East Tennessee State Men’s Soccer, fall 2014.

Publications:

Moreira, S.R., Nobrega, O.T.; Santana H.A.P., Sales, M.P.M., Farinatti, P.T.; Simoes, H.G. Impact of ACE I/D Gene Polymorphism on Blood Pressure, Heart Rate Variability and Nitric Oxide Responses to the Aerobic Exercise in Hypertensive Elderly. Revista Andaluza de Medicina del Deporte, Accepted for publication.

Gleason, B. H., Hollins, J. E., Santana, H. A., DeWeese, B. H., & Stone, M. H. (2014). Performance Training Guidelines for the 1.5 and 2-Mile Runs. Journal of Trainology, 3, 11-30.

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Santana, H. A., Moreira, S. R., Neto, W. B., Silva, C. B., Sales, M. M., Oliveira, V. N., ... & Simões, H. G. (2011). The higher exercise intensity and the presence of allele I of ACE gene elicit a higher post-exercise blood pressure reduction and nitric oxide release in elderly women: an experimental study. BMC cardiovascular disorders, 11(1), 71.

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