

RELIABILITY AND VALIDITY OF THE JUST JUMP® MAT
COUNTERMOVEMENT PUSH-UP HEIGHT AS A
MEASURE OF UPPER-BODY POWER

by

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ABSTRACT

Currently there is little research that has quantified the countermovement push-up (CMPU) power indices or investigated the validity and reliability of the CMPU as a practical upper-body muscular performance test. The current study investigated the force-time characteristics of the CMPU, the reliability and validity of the Just Jump® mat (JJ) to assess CMPU height as an index of upper-body extensor muscular performance. Fifteen trained participants (13 = males and 2 = females); (mean \pm SD) age = 26.87 \pm 2.72 yrs, height = 178.83 \pm 7.92 cm, body mass = 84.85 \pm 15.53 kg, and bodyfat percent = 17.31 \pm 6.20 % were recruited from the University of Utah and the Department of Exercise and Sport Science. The CMPU vertical displacement (CMPU-Ht), measured with 3-D motion analysis (MA) was 24.64 \pm 7.01 cm. A force platform was used to measure peak rate of force development (PRFD) = 6,254.93 \pm 4409.89 N·s⁻¹, peak power (PP) = 329.15 \pm 178.06 W, impulse (IMP) = 198.40 \pm 77.99 N·s, and peak force (PF) = 477.74 \pm 179.73 N. A significant correlation ($r > 0.70$) was observed between motion analysis CMPU-Ht and PF and PP. Given the high relationship between CMPU-Ht and PP and PF, potential use of the use of JJ-derived Ht as a measure of upper body extensor performance was examined. While there was some support for the reliability of the JJ measures of CMPU-Ht, large coefficient of variation % (> 10%), standard error of measurement, random error, and statistical differences ($p < 0.05$) between the motion analysis and Just Jump mat® derived CMPU-Hts suggest that the JJ should not be used to

assess CMPU power. Furthermore, through analyses of JJ CMPU-Ht for construct, convergent, and divergent validity demonstrated that the CMPU-Hts derived with the Just Jump mat® had low validity. Further research is needed to determine if another contact mat or CMPU protocol may improve the reliability and validity of the CMPU as an upper-body extensor muscle performance test.

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CHAPTER 1

INTRODUCTION

Numerous exercises have been used to develop upper-body extensor muscular performance (Hrysomallis & Kidgell, 2001); frequently, the same exercises are used to evaluate or test performance. The countermovement (a movement in the direction opposite to the goal direction) push-up (CMPU) is an example of an exercise that has potential as both a training and testing tool. Although the CMPU is used as a training exercise by strength and conditioning coaches, there is a paucity of research literature focusing on the CMPU as a valid and reliable measure of upper-body performance. One force-time characteristic is power, which is defined as work per unit of time, and is equal to force (F) times distance (D) divided by time (t) ($\text{Power} = F(D/t)$ or force multiplied by time (Zatsiorsky & Kramer, 2006). Execution of a CMPU requires short duration muscle actions by the upper-body musculature, lending support to the logic that the CMPU might be used to assess upper-body extensor muscular performance (Zatsiorsky & Kramer, 2006); but research support for the use of the CMPU as an upper-body muscular performance measure is lacking.

Based upon my interest in the application of sport science to training the upper-body muscular performance of athletes, I recognize that there is a need to examine the viability of the CMPU as a field test for measuring upper-body muscular performance among a broad spectrum of athletes. This dissertation seeks to extend the work of

Hrysomallis and Kidgell (2001) and increase understanding of the force-time characteristics of the CMPU. Hrysomallis and Kidgell used an explosive push-up to assess the influence of heavy resistive exercise on acute upper-body performance. These researchers used a force platform to document several force-time characteristics associated with the execution of an explosive push-up, which may also be called a countermovement push-up. Only male participants were involved in the Hrysomallis and Kidgell study and so there is a need to determine force-time characteristics for both male and female participants with differing training characteristics. There is also a need to begin the exploration of the CMPU as a practical test for assessing upper-body performance.

Although there is little research on the CMPU, there has been considerable research on the countermovement jump (CMJ) height (Figure 1.1), which can be used to both test and train lower-body muscular performance (Aragón-Vargas, 2000; Caruso et al., 2010; Ferreira, Schilling, Weiss, Fry & Chiu, 2010; Kubo, Kawakami, & Fukunaga, 1999). Examination of the CMJ literature could be used to inform understanding of the force-time characteristics of the CMPU.

Countermovement Vertical Jump

Examination of the influence of a countermovement on lower-body power has been approached by comparing force-time variables between the CMJ and vertical jumps with no countermovement (Markovic, Dizdar, Jukic, & Cardinale, 2004). Specifically,

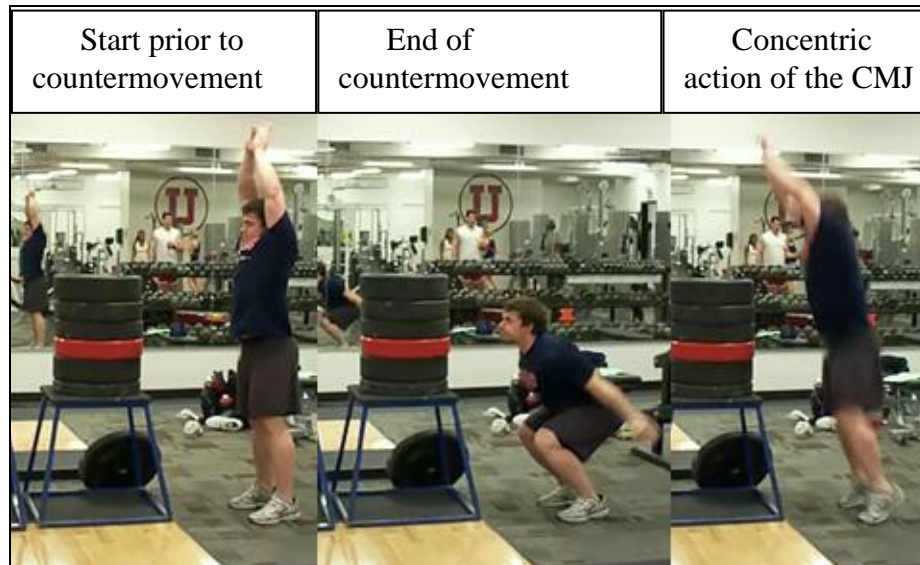


Figure 1.1: The three phases of a counter-movement jump

Bobbert, Gerritsen, Litjens and VanSoest (1996) contrasted a CMJ and squat jump (SJ). The CM portion of a CMJ involves lowering the body's center of mass with an eccentric action of the leg extensors (yielding work) followed by a quick reversal of the motion due to a concentric action of the leg extensors (see Figure 1.1). The SJ does not incorporate a CM, but instead the SJ begins from a static squat position. The CMJ consistently results in a higher vertical jump height, interpreted as greater power output (watts), than the jump height with a SJ. Bobbert et al. (1996) have proposed several factors that might account for the greater jump height of the CMJ. By better understanding of the factors associated with the CM that seem to account for the greater jump heights and power indices achieved in the CMJ compared to the SJ, insight into the CM of the CPMU may also be attained.

The first proposed factor accounting for the increased power output for the CMJ compared to the SJ is that the CM allows more time for the development of force. Based upon analysis of the movement of the jumpers' center of mass, Bobbert et al. (1996)

observed that more mechanical work was produced in the CMJ than SJ ($p < 0.05$). These observations support the premise that higher jump heights with the CMJ may be attributed to the leg extensor muscles developing force prior to their concentric contraction as a result of a CM action. In other words, the time that it takes to lower the center of mass and then reverse direction with the concentric action provides more time to develop maximal force during the CMJ than is available with the SJ (Bobbert et al., 1996; Bosco, 1997; Komi & Bosco, 1971).

A second possible factor for the greater jump heights with the CMJ compared to the SJ is that the CM in the CMJ allows for greater storage and utilization of elastic energy (Komi & Bosco, 1971). The eccentric action that occurs during the CM is thought to stretch or lengthen the parallel elastic component (PEC) and the series elastic component (SEC); (Åstrand, Rodhal, Dahl & Strømme, 2003; Lundlin & Berg, 1991; Sheppard, Newton and McGuigan, 2007) of the extensor muscles. The PEC is comprised of the epimysium, perimysium, and endomysium (see Figure 1.2) whereas the SEC is comprised of the fascicles, muscle fascia, tendon, and muscle proteins (Potach & Chu, 2008). The PEC and SEC contribute to force production because of the passive force that is generated by the stretching of the PEC and SEC, which causes the storage of elastic energy. The stored elastic energy may be released as the muscle actively begins contraction (Potach & Chu, 2008) and therefore be a contributor to force production. Sheppard et al. (2007) demonstrated an increase in jump height through the application of an extra load during the eccentric phase of the CMJ executed by volleyball players. These researchers theorized that the extra loading during the eccentric action resulted in more SEC and PEC deformation (stretch), contributing to the storage of more elastic

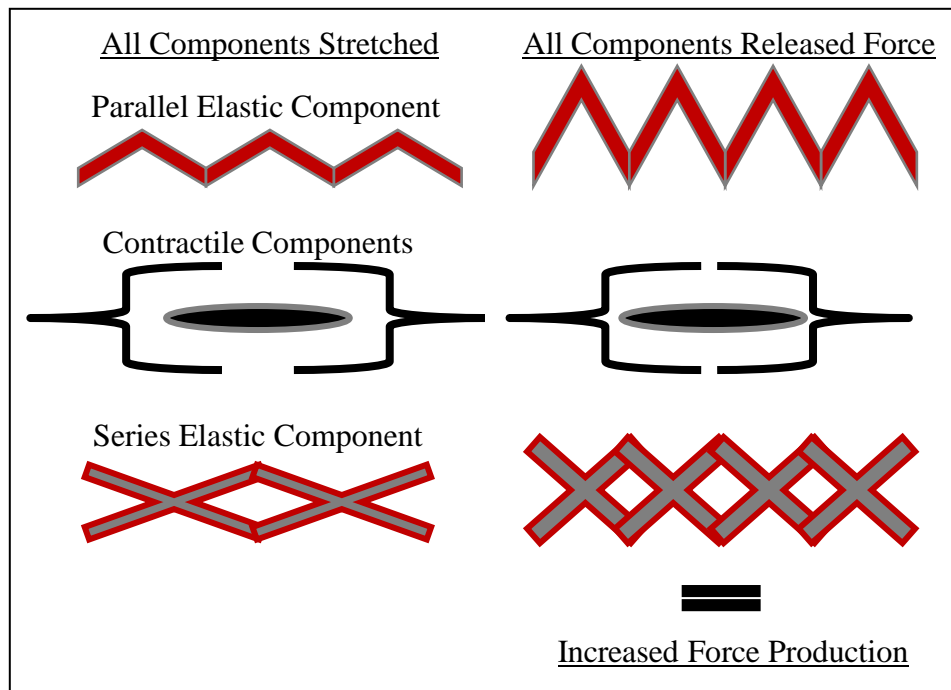


Figure 1.2: The combination of the PEC, Contractile Components, and SEC to increase force production (Left side depicts the CM or eccentric actions and the right represents the concentric actions).

energy and thereby helping to account for the increased CMJ height of the volleyball players.

Bobbert et al. (1996) used a CMJ simulation model to determine if the storage and reutilization of elastic energy enhanced CMJ performance. Their findings lead them to conclude that storage and reutilization of elastic energy may increase the efficiency of the positive work, but storage and reutilization of elastic energy does not increase work produced during the CMJ. Bojsen-Møller, Magnusson, Rasmussen, Kjaer, and Aagaard (2005) examined the contribution of stored elastic energy to the increase in jump height achieved with a CMJ compared to a SJ by examining the relationship between the enhancement in jump height from the SJ to CMJ and tendon stiffness. No relationship

was observed between the difference in jump heights and the tendon stiffness, indicating that storage and utilization of elastic energy is not a major contributor to the increased jump height with a CM. Kubo et al. (1999) also reported that extensor tendon stiffness was not related to absolute jump height for either the SJ or CMJ.

The stored elastic energy as a result of an eccentric action will only contribute to increased force production if the time period between storage and release of the elastic energy is a brief period of time (LaStayo et al., 2003). If the time period between storage and release of elastic energy is too long (e.g., > 250 ms), the stored elastic energy dissipates as heat (Anderson & Pandy, 1993). Based upon the research of Bojsen-Møller et al. (2005) and Kubo et al. (1999) coupled with the relatively long time period for the execution of a CMJ, it is unlikely that the storage and reutilization of elastic energy is a major factor accounting for the greater jump heights and power achieved with a CMJ compared to a SJ.

Another possible explanation for the greater jump heights with the CMJ compared to the SJ is that reflex responses to the stretching of the extensor muscles during the CM of the CMJ result in more leg muscle extensor force production than is true for the SJ. The stretch reflex is the reflex that is most frequently cited as a possible contributor to power production during a CMJ. The stretch reflex is initiated when there is a rapid stretch to a muscle. The rapid stretch is detected resulting in a signal being propagated along a type Ia afferent to the spinal cord (Enoka, 2002). The type Ia afferents are spiraled around the equatorial regions of the nuclear chain and bag fibers (types of intrafusal fibers), whereas the type II afferents are nonspiraled receptors associated with chain fibers (Enoka, 2002). The signal, resulting from the rapid stretch of a muscle,

reaches interneurons in the spinal cord causing the excitation of α motor neurons. The α motor neurons innervate the extrafusal fibers and when activated, initiate a shortening of the contractile components (see Figure 1.3) of the stretched muscle. If this reflex-stimulated shortening occurs simultaneously with the volitionally stimulated shortening contraction, it is reasoned that the force generated by the reflex contraction might augment the force generated by the volitional contraction.

Because the eccentric portion of the CMJ stretches the leg extensor muscles, it has been theorized that the stretch reflex of the leg extensor muscles might contribute to the increased force production and jump heights that have been observed in the CMJ compared to the SJ. The stretch reflex mechanism is thought to be activated with rapid stretching during the eccentric and reversal portions of a movement; but the eccentric and reversal portions of the CMJ may require more than 250 ms (Schmidtbleicher, 1992), which suggests that the contribution of the stretch reflex to the CMJ may be negligible (Enoka, 2002). Electromyographic data collected during both CMJ and SJ have not substantiated that there is more muscle activation [stimulation] during the CMJ than the SJ, supporting the conclusion that reflexes are not contributing to the higher CMJ jump height than SJ height; however, Bobbert et al. (1996) did go on to suggest that more research is needed before the contribution of reflexes to the increased height and power with the CMJ can be completely ruled out.

A final factor that has been proposed to account for the greater jump heights and power output (watts) observed for the CMJ compared to the SJ is that the pre-stretching of active muscles alters the properties of the contractile component (CC) machinery. In

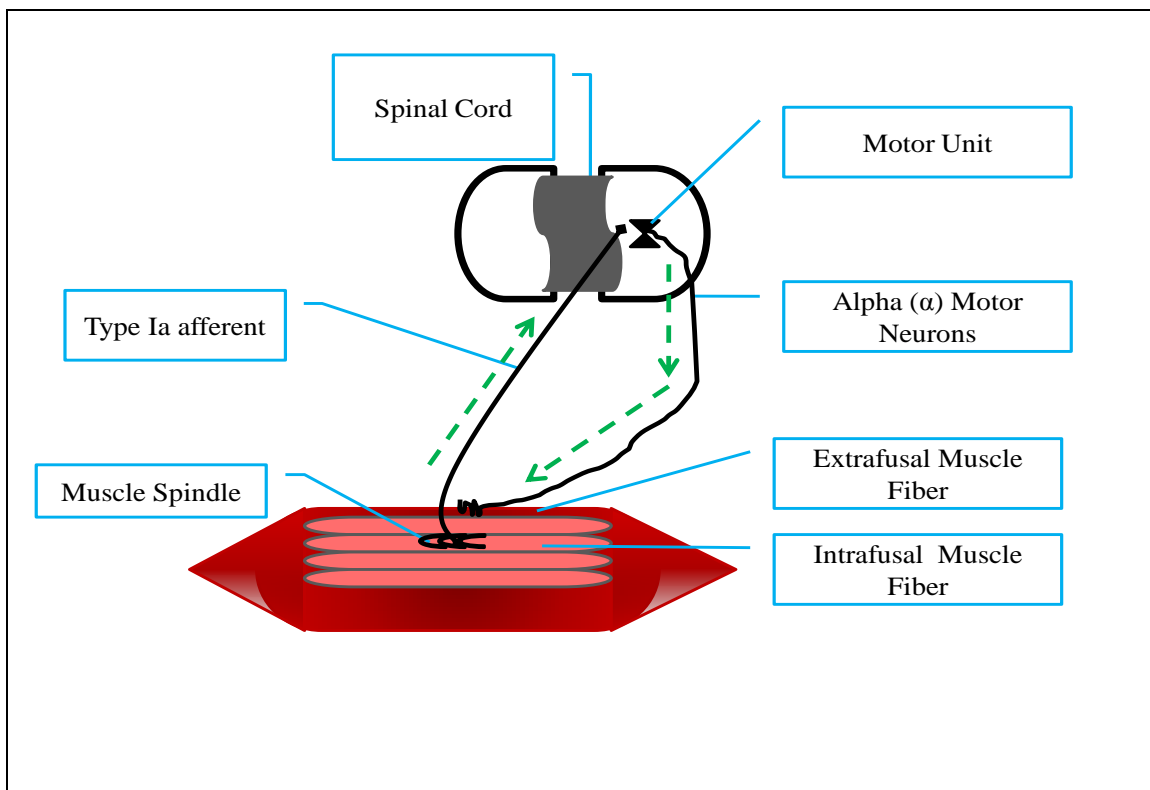


Figure 1.3: Pathways illustrating the stretch reflex via muscle spindle stimulation and the subsequent signal through a Type 1a afferent ending with Alpha Neuron activation.

isolated muscle preparations, pre-stretching of the muscle increases the force production relative to force production in muscle preparations that have not been pre-stretched.

Bobbert et al. (1996) have, however, discounted the importance the pre-stretch potentiating effect on CMJ height and power output (watts), particularly because the speed of the pre-stretch in the CMJ is relatively slow and there is a relatively long time delay (more than 250 ms) between the end of the pre-stretch and the point of maximal power output (watts) production at the joints during the CMJ.

In summary, even though there is still debate as to the relative contribution of the CM factors that might account for the increased height and power output associated with the CMJ compared to the SJ, there is universal agreement that the CM is responsible for the increased height and power output production observed with the CMJ. Therefore, it is reasonable to theorize that the addition of a CM to the push-up should increase the force-time characteristics of a push-up. Unfortunately there is little research associated with the CM and upper-body extensor muscular force-time characteristics, especially with the push-up.

Upper-Body Performance Tests

Historically, the majority of techniques for assessing muscular performance have focused on the lower extremity (particularly the hip, knee, and ankle extensors) movements of the SJ, CMJ, standing and running long jumps. Although there is a small body of research literature focusing on upper-body performance tests, there is not a “gold standard” test for upper-body performance, nor is there a widely used practical test.

Laboratory-based Tests

The 1 repetition maximum (RM) bench press is universally recognized as a gold standard test of absolute strength. Consequently several researchers have sought to develop bench press explosive-strength tests (Cronin & Owen, 2004; Shim, Bailey, & Westings, 2001; Wilson, Murphy, & Pryor, 1994). These upper-body performance tests have used relatively expensive laboratory equipment to directly measure power production (watts) during a bench press or measure bar time during a bench press and

then calculate force-time characteristics (Clemons, Campbell, & Jeansonne, 2010; Cronin & Owen, 2004; Falvo, Schilling, & Weiss, 2006; Shim et al., 2001). In addition to establishing the logical validity of bench press force-time tests, Clemons et al. (2010) compared their bench press power (BPP) test to a modified Smith machine force-time (SMP) test to provide evidence for the concurrent validity of these upper-body performance tests. They reported that there was not a statistically significant difference between the two resultant upper-body extensor force-time values. The mean power output values were 521 ± 153.5 watts and 538 ± 192.1 watts for the BPP and SMP test, respectively. Clemons et al. (2010) examined the reliability of the proposed bench press power test and observed a high intraclass correlation (ICC) of $R > 0.90.$, in support of test-retest reliability over a 2' week test period. Shim et al. (2001) demonstrated similar results for test – retest reliability. However, neither Clemons et al. (2010) nor Shim et al. (2001) reported other evidence in support of reliability as suggested by Atkinson and Nevill (1998) and Hopkins, Schabert, and Hawley. (2001).

Because power is a function of force relative to time, an approach to assessing upper-body force-time characteristics has been to use expensive instrumentation (e.g., force platform) to measure rate of force development during bench presses performed differently (Wilson et al., 1994). The maximum rate of force development (RFD) values during concentric (30% of single maximal effort), eccentric (130% of single maximal effort), and isometric (elbow angle at 120°) bench presses were $12,223.2 \pm 2,688.8$ N·s, $14,652.5 \pm 3,546.2$ N·s, and $12,149.6 \pm 4,734.9$ N·s, respectively.

To provide evidence in support of using RFD as a valid measure of upper-body force-time characteristics, Wilson et al. (1994) reasoned that musculotendinous stiffness

is associated with the potential for greater storage of elastic energy and therefore greater force-time characteristics production potential. Wilson et al. (1994) examined this hypothesis by determining the relationships between RFD and musculotendinous stiffness and they reported moderate and statistically significant relationships between musculotendinous stiffness and concentric and isometric bench press RFD, $r = 0.65$ and 0.78 , respectively providing evidence for the concurrent validity of RFD during concentric and isometric bench presses as measures of upper-body performance. Their observations lead Wilson et al. (1994) to state that “A stiff musculotendinous unit appears to enhance the force production capacity of the contractile component through a combination of an improved contractile component length and rate of shortening” (p. 2179). Furthermore, Wilson, Lyttle, Ostrowski, and Murphy (1995) demonstrated that RFD was a possible predictor of “good” or “poor” sprinting performance, which could lead to the inclusion of assessing RFD as a variable for assessing the force-time characteristics of an exercise.

Although there is increasing evidence in support of valid and reliable laboratory-based assessments of upper -body performance, the cost of the laboratory equipment and the time burdens for both the test administrator as well as the athlete make wide spread use of laboratory-based upper-body performance tests impossible. Therefore there is a need for practical tests of upper-body performance tests.

Practical Tests

The medicine ball put test is touted as a field test for assessing upper-body extensor power that has been used for more than 30 years (Mathews, 1973). Cronin and

Owen (2004) observed $R = .86$ for medicine ball chest throw whereas Davis et al. (2008) demonstrated medicine ball chest throws in kindergartners had a within day correlation of $R > 0.90$ and a test-retest $R = 0.88$. Additionally, Clemons et al. (2010) demonstrated ICC R values of > 0.92 for medicine ball chest throw and bench press power tests. Furthermore, Cronin and Owen (2004), using the guideline of a coefficient of variation (CV%) of less than 10% (Atkinson & Nevill, 1998) as being supportive of test reliability, reported intratrial reliability CV% values below 3.50% for medicine ball puts. The previously mentioned studies varied in time between test trials from 24 hours to 7 days.

Along with providing data in support of the reliability of the medicine ball put, a number of sport scientists have contributed to establishing support for the validity of the medicine ball put as a measure of upper-body performance. Davis et al. (2008) correlated the medicine ball throw distances of 5-6 year olds with a modified pull up performance and used Pearson Product Moment correlations to quantify concurrent validity. The r of 0.34 indicated only moderate validity; however, there is some question as to whether a modified pull up is an appropriate criterion measure for determining the concurrent validity of a measure of upper-body performance. Cronin and Owen (2004) compared seated medicine ball chest throws to impulse, peak force, peak power, mean power, and maximal strength to provide evidence of convergent validity. All of the resultant r values were greater than 0.60, supporting convergent validity. Clemons et al. (2010) used a modified Smith machine bench throw as the criterion measure to examine the concurrent validity of medicine ball chest throws. The resultant r value was > 0.70 . Furthermore, Clemons et al. (2010) gathered validity evidence by correlating medicine ball chest throws and bench press power test values using Pearson Product Moment correlation.

They reported coefficients of $r = 0.86$ ($p < 0.01$) for males and $r = 0.79$ ($p < 0.01$) for females.

Although considerable evidence in support of the reliability and validity of the medicine ball put or throw as a measure of upper-body performance across a number of different population groups exists, medicine ball power tests do not adequately meet the ease of administration criterion necessary for a true practical upper-body performance test. The major problems associated with testing large groups of athletes using a medicine ball put is the time necessary to process all of the athletes. A practical test that individuals of varying abilities could perform in a relatively time efficient manner is still needed. The push-up is an exercise that is widely used by individuals, perhaps some modification of the well known push-up could be used as a measure of upper-body force-time characteristics.

Push-ups

One of the most frequently used muscular performance tests is the timed push-up test. In this test, the maximum number of push-ups that can be completed in a set time period (i.e., 1 minute) is recorded (Baumgartner et al., 2004). The push-up is also a commonly used exercise in training programs, leading some sport scientists to examine the push-up as a possible tool for assessing upper-body force-time characteristics. However, the validity of using a push-up test as a measure of upper-body strength has been questioned by Invergo et al. (1991). These researchers compared timed push-up performance with maximal bench press strength and reported that the timed push-up scores only accounted for 31% of the variance of the maximal bench press strength

values. Based upon these results, Invergo et al. (1991) concluded that a timed push-up test is a poor procedure for determining upper-body maximal strength.

If timed push-ups are a poor predictor for maximal strength then it is unlikely that timed push-ups would be an appropriate test for upper-body performance. A timed push-up test is more appropriately classified as a muscle endurance test, reflecting a high capacity for muscular endurance rather than the high speed muscle contractions necessary for producing muscular force-time characteristics. Conceivably the addition of a countermovement to the push-up may allow the athlete to generate muscular performance to propel the upper-body into the air, resulting in a countermovement push-up (CMPU). The addition of a CM to the vertical jump has resulted in a lower-body power test widely used by coaches and sport scientists. Perhaps the same might be true for the addition of a CM to the push-up.

Cronin, McNair, and Marshall (2001) have provided insight into the impact of the addition of a CM to a bench press. The addition of a CM to a bench press throw increased the throwing force by 14.1% and peak bench press throw power increased by 11.7% across all loads (30 - 80% 1-RM) utilized. No similar comparisons are available for the addition of a CM to the push-up, but Hrysomallis and Kidgell (2001) have used what they term an explosive push-up to assess acute upper-body performance. The explosive push-up begins with a counter movement and so it could be termed a countermovement push-up (CMPU). The Hrysomallis and Kidgell (2001) force platform data appear to be the only published values for CMPU power; however, the use of a force platform would preclude the CMPU being used as a practical upper-body performance test.

The countermovement jump (CMJ) test has enjoyed widespread use as a practical lower-body performance test because the height of the jump has been established as a valid surrogate for various force-time characteristics (McLellan, Lovell, & Gass, 2011). If strength and conditioning coaches are to be able to use the CMJ as a training exercise and as a practical way to measure upper-body performance, there is a need to understand the force-time producing characteristics of the CMJ, the relationship between CMJ performance and CMJ vertical displacement, as well as a practical way to measure CMJ vertical displacement.

Assessing CMJ Vertical Displacement

Although the CMJ can be used as an upper-body performance training exercise, measurement of the height off the ground achieved during the CMJ is not as easily obtained as is jump height from a CMJ. For the purposes of gathering evidence in support of using CMJ height as a measure of upper-body performance, 3-D motion analysis can be used to measure CMJ height.

The development of a practical upper body performance test is contingent on being able to use a piece of equipment that is much less expensive than a 3-D motion analysis system and still yields reliable and valid measures of the vertical displacement that occurs during the execution of a CMJ. The Just Jump® mat is a tool that has been developed and used to assess lower body force-time characteristics by predicting vertical jump height from flight time. By examining the Just Jump® mat's reliability for gathering vertical displacement associated with the CMJ, development of a practical upper-body performance assessment tool might be possible. The Just Jump® mat

assesses vertical jump height (VJ-Ht) through the measurement of flight time the person is not in contact with the ground.

Research Problems

A push-up that uses a CM action prior to the concentric phase may provide an easily applied test that could be used for all levels of athletes in multiple settings. The CM action can create a greater vertical displacement than if a person performs an explosive push-up starting from the ground. A CMPU may invoke similar muscular actions in the upper-body muscular extensors as a CMJ in the lower-body musculature allowing for the assessment of upper body force-time characteristics. Only Hrysomallis and Kidgell (2001) have reported force-time characteristics associated with the CMPU. Therefore, there is a need to extend the work of Hrysomallis and Kidgell (2001) and assess the power indices associated with CMPUs performance by both men and women and weight trained individuals as well as aerobically trained individuals. There is also a need to determine if vertical displacement during a CMPU or CMPU height can be used as a surrogate measure of upper-body performance. Lastly, if the CMPU is to be used as a practical test of upper-body performance, inexpensive instrumentation that can reliably and accurately measure CMPU height is needed.

Research Studies

The following three studies have been designed to address the above research problems. The study titles and associated research questions are presented below:

Study 1

The first study is entitled, “Force-Time Variables of the Countermovement Push-up.” The study addresses two research questions:

1. What are the force-time characteristics (peak rate of force development, peak force, impulse, and peak power) of the countermovement push-up?
2. Can the vertical height displacement of the CMPU be used as a measure of upper-body performance?

Study 2

The second study is entitled, “Reliability of Countermovement Push-up Height Derived with a Just Jump® mat.” The study research question is, “Does the Just Jump® mat measured countermovement push-up height have internal consistency and test-retest reliability?”

Study 3

The third study is entitled, “Validity of Countermovement Push-up Height Derived with a Just Jump® mat.” The study addresses three research questions:

1. Are there significant mean differences between the Just Jump ® mat and 3-D Motion Analysis Capture Method as measures of countermovement push-up vertical displacement?
2. Is there agreement between the Just Jump ® mat countermovement push-up vertical displacement and the force platform force-time characteristics of peak rate of force development, peak force, impulse, and peak power?

3. Are there relationships between Just Jump ® mat countermovement push-up vertical displacement and bench press strength or 1-minute push-up test results?

Assumptions

The results of the above studies were interpreted with the following assumptions:

1. The 3-D Motion Analysis Capture Method provides a valid measurement of countermovement push-up vertical displacement height.
2. The use of a consistent, self-selected hand position for each countermovement push-up will decrease the variability between repetitions.
3. The countermovement push-up is an exercise that demonstrates upper-body muscular extensor performance.
4. Participants will exert a maximal effort during each countermovement push-up.

Delimitations

This study is delimited as follows:

1. The selection of participants was delimited to only recreationally trained, collegiate males and females from the Salt Lake City, Utah, USA, area. Therefore, this sample is not representative of all individuals around the United States.
2. The participants met inclusion criterion in order to participate in this study. Only collegiate males and females, ranging from 18-35 years with no acute or

chronic musculoskeletal injuries that would interfere with countermovement push-up capability participated in the current study.

3. A wooden template with measurement distances was used to standardize hand position for the participants and reduce in the execution of the C MPU.

CHAPTER 2

FORCE-TIME VARIABLES OF THE COUNTERMOVEMENT PUSH-UP

The countermovement jump (CMJ) is used to develop and measure lower body extensor performance. One of the reasons that the CMJ can be used as both a training exercise and an assessment tool is that various force-time variables of the CMJ have been described and documented; revealing that vertical displacement during a CMJ or jump height is related to leg extensor force-time variables (Komi, 2000). In addition, it is relatively easy and inexpensive to measure vertical jump height or predict jump height from time-in-the air during a CMJ (Tomchuk, 2011), further contributing to the widespread use of the CMJ as a practical test for lower-body performance. Unfortunately less is known about displacement height and the force-time variables of another countermovement exercise, the countermovement push-up (CMPU).

Hrysomallis and Kidgell (2001), while examining the influence of heavy dynamic resistive exercise on acute upper-body muscular extensor performance, used an explosive push-up or CMPU as a measure of acute upper-body muscular extensor performance. The CMPUs were performed with the hands placed on a custom-built strain gauge force platform. A mean maximum rate of force development (RFD) of 4 s were observed, but CMPU vertical displacement was not measured. If the CMPU is to be used as a practical

test of upper body muscular extensor performance as is done with the CMJ, the observations of Hrysomallis and Kidgell (2001) need to be extended by assessing CMPU vertical displacement and examining the relationships between vertical displacement and CMPU force-time variables. Therefore, the purpose of this study was to determine peak force (PF), peak power (PP), peak rate of force development (PRFD), impulse (IMP), and vertical displaced (Ht) during the execution of a CMPU. The relationships between CMPU-Ht and the force-time variables were also examined.

Methods

Experimental Approach to the Problem

A cross-sectional design was used to observe force-time variables associated with the execution of the CMPU. The 15 volunteer participants reported to the laboratory on three separate occasions. The first laboratory session served as an opportunity for collecting demographic information and familiarizing the participants with the CMPU protocol. During the second and third laboratory sessions, test-retest of the CMPU force-time variables and CMPU-Ht was completed. A three-dimensional motion analysis system was used to obtain CMPU-Ht and a force platform was used to obtain the CMPU force-time variables of PP, PF, IMP, and PRFD.

Participants

All participants in this investigation completed a consent form and were informed of the requirements of the study, which was conducted with the approval of the

University of Utah Institutional Review Board. Fifteen participants (13 = males and 2 = females); (mean \pm SD) age = 26.87 ± 2.72 years, height = 178.83 ± 7.92 cm, body mass = 84.85 ± 15.53 kg, and bodyfat percent = 17.31 ± 6.20 % were recruited from the University of Utah. Participants were classified as trained with a mean training frequency of 3.47 ± 0.99 days per week and a mean training time of 57 ± 15.21 minutes per training session. Eleven of the participants were engaged in strength training programs. Four of the participants did not engage in strength training on a regular basis, but they were aerobically exercising, playing basketball, or engaging in muscular endurance training. Participants who were previously diagnosed by a physician with any musculoskeletal disease or soft tissue injury that might impair their ability to execute a C MPU were excluded from the study.

Initial Laboratory Session

A schematic of the study timeline is presented Table 2.1. For the initial laboratory session the following descriptive data were collected:

Body mass. Participant's BM was obtained on an IQ plus 355 weight indicator (Rice Lake Weighing Systems, Inc., Rice Lake, WI) and recorded to the nearest 0.01 kilograms.

Height. HT was measured barefoot with a wall mounted ruler in centimeters (cm) and recorded to the nearest millimeter.

Body composition. Body-fat percentage (BF%) was calculated using a seven site formula (American College of Sports Medicine, 2006). All seven SKF sites were

Table 2.1: Timeline for the study. (TT= Test Trial)

Timeline				
<i>Initial Trial</i>	1-2 Weeks	<i>TT1</i>	48-72 hours	<i>TT2</i>

measured by the lead investigator who has 20 years of experience using the Lange Caliper (Beta Technology, Santa Cruz, CA).

CMPU practice. Timed push-up (PU) tests have frequently been used to determine upper-body strength (Invergo et al., 1991; Tomchuk, 2011); however, utilization of the timed PU seems to be a poor method for assessing strength or power (Invergo et al., 1991). One element of the timed PU test that detracts from its utility as a measure of muscular strength is that the PU requires the upper-body muscles to move only 60% of a person's body mass (Gouvali & Boudolos, 2005; Hrysomallis & Kidgell, 2001). The movement of a relatively light load and the multiple repetitions characteristic of the timed push-up test makes the timed PU test a muscular endurance test rather than a muscular strength test. The addition of a countermovement to the push-up; however, creates the opportunity for more of a power test based upon the research of Cronin et al. (2001) and Falvo et al. (2006). These researchers have previously reported that the addition of a CM to the bench press significantly increased the power characteristics of the bench press.

Because the CMPU may be a novel exercise, following an upper-body dynamic warm-up (DWU) (Table 2.2) the participants were introduced to the CMPU. Prior to executing the CMPU, the participants were instructed to select a comfortable hand position. Self-selected hand position was used because hand position has been shown to influence the muscle activity of the upper-body muscles during a push-up. If the hand position is too narrow, higher muscle electromyographic activity (EMG) occurs, but a

Table 2.2: Upper-body dynamic warm-up

<ol style="list-style-type: none"> 1. Jumping jacks 1 minute 2. Push-ups x10 3. Body weight squats x10 4. Dynamic Hip Flexor stretch “Scorpions” x10 each leg 5. Horizontal Arm swings – Forward & Backward x10 each direction 6. Sagittal Arm swings – Forward & Backward x10 each direction 7. Standing torso rotation x20

lower maximal vertical force (F_z) is observed than when a wider hand position is used (Cronin & Owen, 2004; Gouvali & Boudolos, 2005). Self-selection of hand position for performing the CMPU allowed participants to be in a position that they deemed to be the optimal. As a strategy for improving consistency between trials, the self-selected hand position width was recorded as centimeters deviation from the center point of a template. This hand position was replicated for all CMPUs completed for the study.

Each CMPU was initiated with the hands on the force plate, elbows fully extended, shoulders flexed to approximately 90° , torso and legs extended, and feet together with toes and balls of feet in contact with the ground. Participants then rapidly lowered their chest, but just before contact with the force platform, they quickly changed directions pushing their body into the air until the elbows were fully extended and hands broke contact with the force platform (Hrysomallis & Kidgell, 2001; Lyttle, Wilson, & Ostrowski., 1996).

Test Trials

The test-retest trials (Figure 2.1) took place 48-72 hours apart to minimize the influence of fatigue and accommodate weekend, school, or work schedules. For TT1, participant body mass was measured and reflective markers for the 3D motion analysis

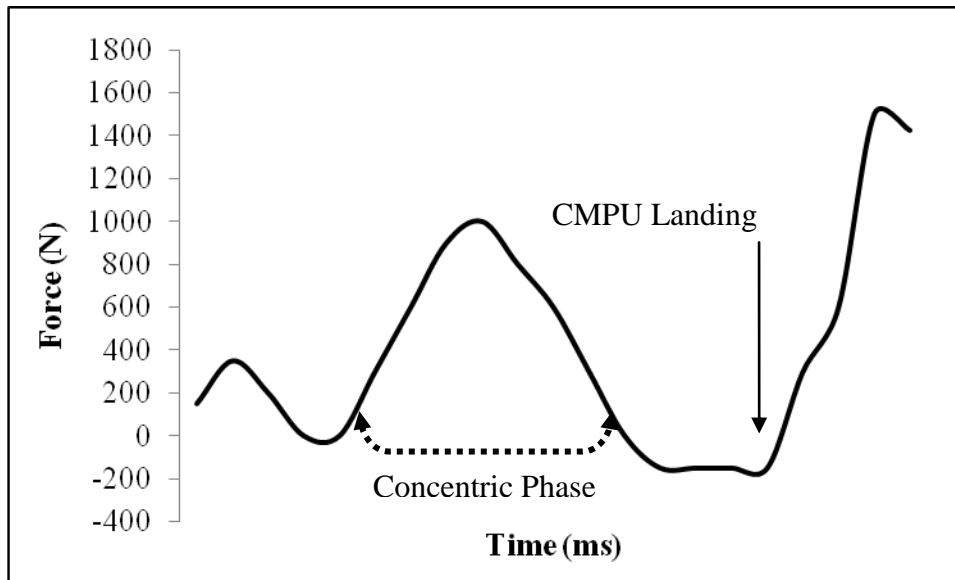


Figure 2.1: Force platform force-time curve of the CMPU

were positioned. The following bony landmarks were used: 3rd metacarpal, radial and ulnar styloid, medial and lateral epicondyles, acromion process, medial superior scapulae spine, medial inferior scapulae apex, right off-set marker, and cervical 7- thoracic 1 spinous process. The reference points for the reflective markers were maintained throughout the study by placing an indelible ink mark over each site. A 10 Camera Raptor-E Digital Real Time Camera System (Motion Analysis Corporation, Santa Rosa, CA) was used to measure CMPU-Ht using the reflective markers. Kinematic data were collected at a sampling rate of 120 Hz and raw data were first processed to eliminate any noise artifact, followed by a low pass filter at 6 Hz using a 2nd order zero lag Butterworth digital filter.

When the reflective markers were in place, the DWU was completed. Participants then performed the CMPUs with their hands positioned on a BP400600 (2000lb capacity) force platform (FP) (Advanced Mechanical Technology, Inc., Watertown, MA), which

was used to measure the force-time variables. Kinetic data were sampled at 400 Hz for the CMPU repetitions.

Participants were instructed to pause prior to each of the 5 CMPU repetitions (Jo, Judelson, Brown, Coburn, & Dabbs, 2010) so that the self-selected hand position could be re-established. All procedures were replicated for TT2. Testing procedures did not need to be interrupted due to participant injury, complaints, or inability to correctly execute a CMPU.

Participant CMPU-Ht was determined by measuring, to the nearest 0.01 cm, the displacement of C7-T1 reflective marker through motion analysis. The TT1 CMPU and TT2 CMPU with the highest PF, reported as N (Newton), was used to obtain the PRFD, PP, IMP, and CMPU-Ht values. Only data during the concentric phase of the CMPU were analyzed. PRFD was determined by using the greatest gradient of 10 consecutive data points that occurred in the first 50 ms of the concentric phase of the CMPU and was reported as $N \cdot s^{-1}$ (Newtons per second; see Figure 2.1). PP was determined by taking the product of PF and CMPU-Ht, and dividing the product by the time from PF to the point of take-off ($P = (f \times d) / t$) and was reported as W (Watts). IMP was calculated by taking the average force from the start of concentric action to its completion then multiplying by the time required for the action to occur ($IMP = F_{avg} \times t$) and was reported in $N \cdot s$ (Newton second).

Statistical Analysis

Descriptive statistics were calculated for the CMPU-Ht, PF, PP, and PRFD values associated with highest CMPU PF during both the TT1 and TT2. Scatterplots, intraclass

correlation coefficients (ICCs), coefficient of variation (CV%), standard error of the mean (SEM), and paired t-tests were used to examine the day-to-day reliability of the CMPU force-time variables. Pearson Product Moment correlations were used to examine relationships between CMPU-Ht and PF, PP, IMP, and PRFD, with an a priori of $r > 0.70$ set to indicate a large relationship (Cohen, Cohen, West, and Aiken, 2003; Shim et al., 2001). All statistical analyses were performed on PASW Statistics 18.0 (Formerly SPSS; IBM Inc., Chicago, IL).

Results

Day-to-Day Reliability

Descriptive statistics for the CMPU FP variables and motion analysis CMPU-Ht, associated with the highest PF value for TT1 and TT2 are presented in Table 2.3. The scatterplots comparing the TT1 and TT2 force-time variables are in Figures 2.2, 2.3, 2.4, and 2.5. The ICCs and associated within subjects CV% and SEM values for the test-retest variables are presented in Table 2.3. The paired t-test between the test-retest PF was significant at the $p = 0.05$ level.

CMPU-Ht Relationships

Because there was a statistical difference between the TT1 and TT2 PF values and the relatively high CV% values associated with the day-to-day reliability data, there may have been a learning effect. Therefore only the values associated with the TT2 PF CMPUs were (see Table 2.3) used to derive the Pearson Product-Moment coefficients for

Table 2.3: Test-retest reliability of force-time variables from motion analysis and force platform (Mean \pm SD)

	TT1(Test)	TT2(Re-test)	ICC	CV (%)	SEM
CMPU-Ht (cm)	23.92 \pm 7.22	24.64 \pm 7.01	0.98	7	1.52
PRFD (N·s ⁻¹)	5403.53 \pm 3893.78	6254.93 \pm 4409.89	0.74	58	2650.84
IMP (N·s)	184.61 \pm 74.02	198.40 \pm 77.99	0.89	20	33.23
PP (W)	299.95 \pm 191.06	329.15 \pm 178.06	0.94	29	61.35
PF (N)	427.67 \pm 181.04	477.74 \pm 179.73	0.95	12	45.59

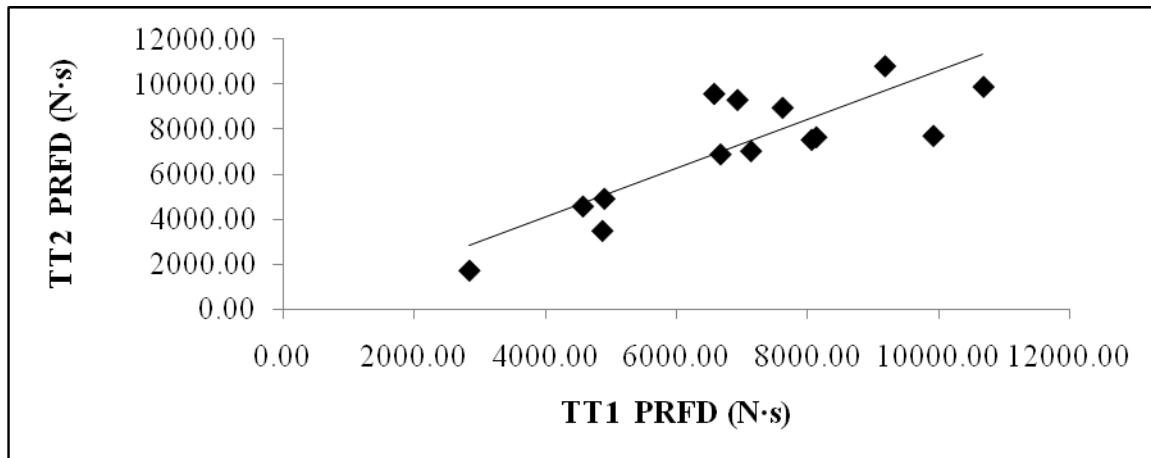


Figure 2.2: Scatterplot of PRFD between TT1 and TT2.

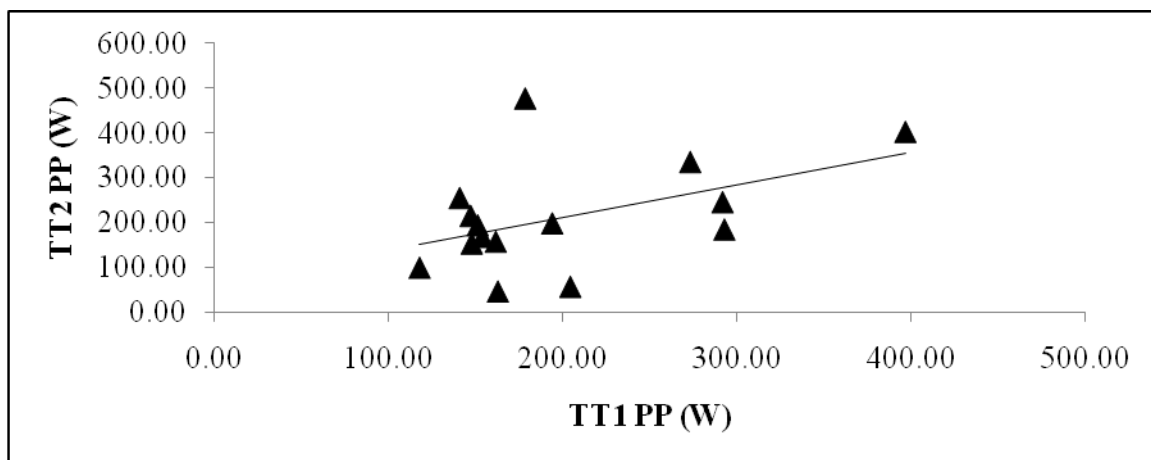


Figure 2.3: Scatterplot of PP between TT1 and TT2.

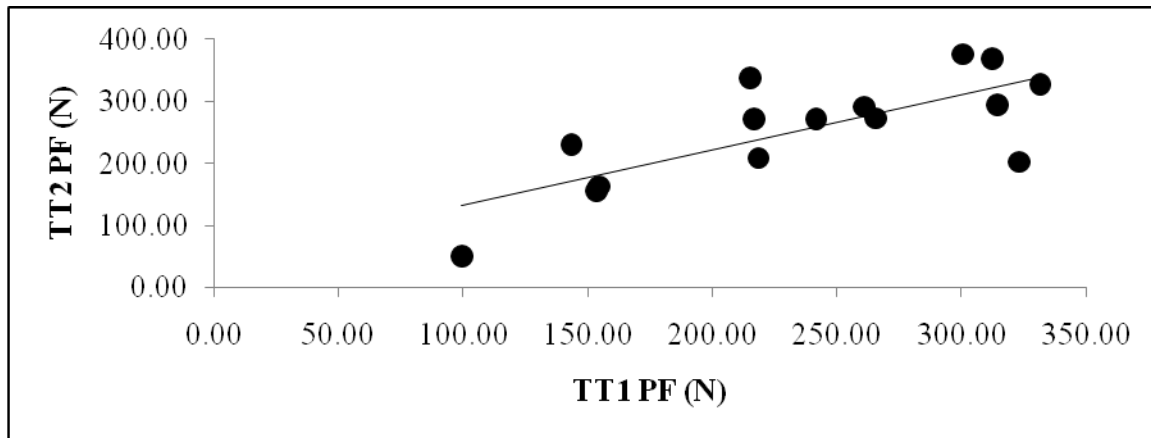


Figure 2.4: Scatterplot of PF between TT1 and TT2.

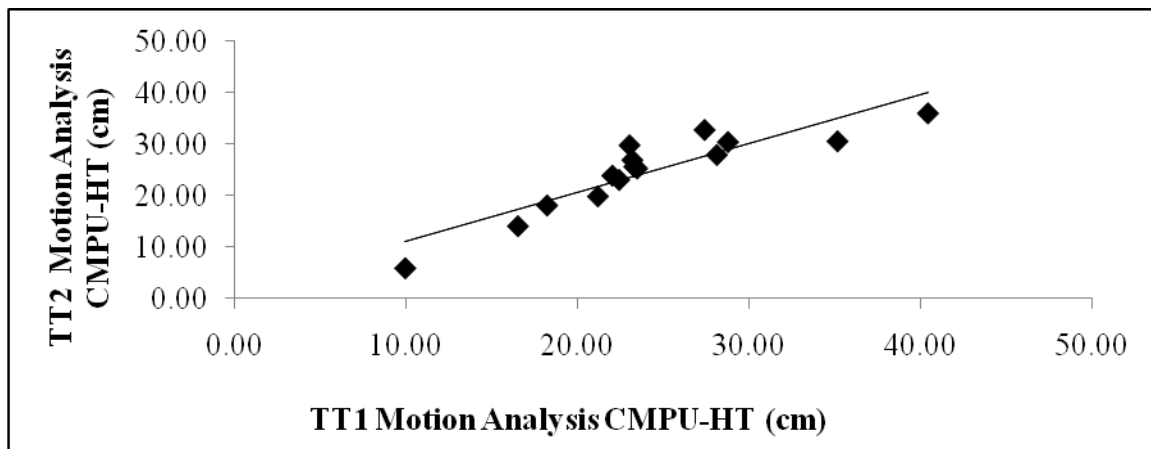


Figure 2.5: Scatterplot of CMPU-Ht between TT1 and TT2.

CMPU-Ht and the force platform derived CMPU force-time variables. The coefficients between CMPU-Ht and FP variables meeting the a priori r of 0.70 are underlined in Table 2.4.

Discussion

The 2001 manuscript of Hrysomallis and Kidgell, to the authors' knowledge, represents the only published force-time variables for the CMPU. Consequently, the

current study was completed to extend the work of Hrysomallis and Kidgell and measure CMPU vertical displacement, which would also allow for the calculation of PP. As may be seen in Table 2.5, peak force platform values from the current study are generally lower than the values reported by Hrysomallis and Kidgell (2001). This disparity probably reflects the variability of the participants in the current study compared to the Hrysomallis and Kidgell study in which all participants were male and recreationally weight trained. The current study (see Table 2.6) included males and females as well as aerobically trained individuals and strength trained individuals. The CMPU-Ht values for the females were approximately half the CMPU-Ht values for the males in the study. Similarly, the aerobically trained participants had lower CMPU-Ht values than did the strength trained participants. Thus the lower values observed for the female and non-weight trained participants probably accounts for the lower mean values in the current study. In spite of the variability in the types of participants, all of the participants in the current study were able to execute a CMPU, demonstrating that a broad spectrum of individuals can execute a CMPU.

As part of the goal of extending the work of Hrysomallis and Kidgell (2001), the current study assessed CMPU-Ht as well as force-time variables to determine the relationships between CMPU-Ht and CMPU force-time variables. Consequently, the most important finding in the current study was the high correlation ($r > 0.70$) between CMPU-Ht and the force platform PF (see Table 2.4). A high correlation between CMPU-

Table 2.4: Pearson Product Moment Correlations matrix between CMPU-Ht and force platform derived force-time variables.

	CMPU-Ht
PRFD	0.43
PF	<u>0.70</u>
IMP	0.56
PP	<u>0.81</u>

Table 2.5: Study comparison of CMPU-Ht and force-time variables means for TT2, and Hysomallis and Kidgell (2001). n/a = not reported in study

Study	CMPU-Ht (cm)	PRFD (N·s⁻¹)	IMP (N·s)	PP (W)	PF (N)
Hysomallis and Kidgell (2001)	n/a	4,726.00 ± 989.00	262.00 ± 43.00	n/a	537.00 ± 148.00
Current Study	24.64 ± 7.01	6,254.93 ± 4409.89	198.40 ± 77.99	329.15 ± 178.06	477.74 ± 179.73

Table 2.6: Participants' status CMPU-Ht and force-time variables means for TT2.

Participant	CMPU-Ht (cm)	PRFD (N·s⁻¹)	IMP (N·s)	PP (W)	PF (N)
Female (n = 2)	11.95 ± 3.06	1011.39 ± 740.10	73.91 ± 43.44	34.63 ± 11.64	139.13 ± 24.50
Male (n = 13)	26.60 ± 5.05	7061.62 ± 4165.96	217.56 ± 62.92	374.46 ± 142.47	529.83 ± 124.85
Weight Trained	25.90 ± 6.37	5989.67 ± 4436.27	209.14 ± 72.63	359.34 ± 177.41	501.87 ± 158.53
Non-Weight Trained	20.59 ± 7.24	8398.46 ± 4676.71	152.77 ± 82.27	284.44 ± 193.56	395.08 ± 218.45

Ht and PF suggests that the assessment of CMPU-Ht might be a strategy for using CMPU-Ht as a measure of upper-body extensor force production.

The correlation between CMPU-Ht and PP was also high, but a high correlation is to be expected because CMPU-Ht is used in the calculation of PP. The TT2 mean PP was 314.55 ± 182.07 W, which is at the lower range of the PP values (303-992 W) observed by Shim et al., (2001) for bench throws. Conversely Cronin and Owen (2004) observed mean PP values for 10 kg bench throws of 161.0 W. Differences in the training status of the Shim and Cronin and Owen participants probably contributed to the differences in PP values, variability in load was probably also a contributing variable. Shim used bench press loads of 75% 1-RM whereas Cronin and Owen used a fixed load of 10 kg. For the CMPU, a portion of individual body weight (approximately 60% sources) serves as the load and even this portion varies between individuals depending upon relative trunk and limb lengths. Given the potential influence of loading on the calculation of CMPU power output and other associated problems with using vertical displacement for the calculation of power output, as has been highlighted in the counter movement vertical jump literature (Knudson, 2009), using vertical displacement for the calculation of power output may not be an appropriate measurement to describe the force-time characteristics of the upper-body extensor muscle executing a CMPU.

Although PP may not be a meaningful value to derive from CMPU-Ht, the high correlation between CMPU-Ht and PF suggests that CMPU-Ht might be a useful indicator of upper body extensor force-time characteristics and thus upper body extensor muscular performance. However, much more research is needed. Although all of the

participants in the current study were able to execute a CMPU, one possible explanation for the poor test-retest reliability for PF and the significantly higher TT2 than TT1 PF value is that the CMPU practice trials did not provide enough time for the participants to learn how to execute the CMPU. Hrysomallis and Kidgell (2001) did not observe a significant difference between their two reliability test days, leading the authors to conclude that the day-to-day reliability of the CMPU was adequate. Hrysomallis and Kidgell (2001) did not report CV% values for their test-retest data, but the relatively large CV% and SEM values for the current study contributed to the conclusion that the participants in the current study needed more time to learn how to execute a CMPU. This conclusion seems warranted given that some of the participants in the current study did not have weight training experience. If the CMPU is to be a reliable test of upper body extensor force for nonweight trained individuals, more research is needed to determine the appropriate number of practice trials to ensure non-weight trained individuals can reliably execute a CMPU.

In addition to PF and PP, PRFD and IMP were observed in the current study because PRFD and IMP have been identified as lower body performance predictors (McLellan et al., 2011). The results are interesting in that neither PRFD nor IMP were highly correlated with CMPU-Ht. The relationship between RFD and vertical jump height is variable, with some investigator reporting a high relationship and others observing a poor relationship between vertical jump (VJ) height and RFD (Knudson, 2009; Weiss, Feldman, Schilling, Ferreira, & Hammond, 2011). A primary explanation for the conflicting results for the relationship between RFD and VJ height is hypothesized to be methodological differences in the determination of RFD. Another factor that may

contribute to the lack of clarity in the literature is the use of separate tests to measure height and RFD. By using motion capture analysis simultaneously with the execution of a CMPU on the force platform in the current study, the limitation of separate tests was removed. In spite of this methodological arrangement, a high correlation between CMPU-Ht and PRFD was not observed. While investigating the role of RFD on vertical jump performance, McLellan et al. (2010) reported low retest reliability for RFD. Low retest reliability was also observed in the current study, perhaps contributing to the lack of a correlation between CMPU-Ht and PRFD.

Studies have demonstrated that varying hand and body position influences vertical forces during push-up actions (Cronin & Owen, 2004; Gouvali & Boudolos, 2005). Therefore it is possible that hand or body position variability between trials contributed to the low retest reliability for the CMPU. However the procedure requiring participants to re-establish their self-selected hand position between CMPU repetitions reduces the possibility that positional changes explain the low retest reliability. Furthermore, the participant's mean shoulder width was 49.28 ± 4.86 cm whereas the participant's hand position was 54.60 ± 6.83 cm demonstrating difference of 5.32 cm.

Summary

A broad spectrum of participants including females and non-weight trained participants can execute a CMPU; however, more research is needed to determine the optimal number of practice trials to prevent a learning effect from reducing the day-to-day reliability of the CMPU. If the high correlation between CMPU-Ht and PF is

consistently observed, practical strategies for measuring CMPU-Ht might be helpful tool for assessing upper body extensor muscle performance.

Application

A wide spectrum of participants can execute a CMPU, including both females and males. Because the vertical displacement achieved during a CMPU is related to peak force produced by the upper body extensor muscles, efforts to assess CMPU-Ht or vertical displacement are warranted. However, care should be taken in interpreting the meaning of CMPU-Ht values. Because the currently study was only a cross-sectional, correlational study care should be taken not to draw cause-effect conclusions from the current study. Consequently practitioners should be careful not to conclude that using CMPUs in training plans will enhance upper-body extensor muscle performance, or that having a high CMPU-Ht will be predictive of high upper body extensor muscle performance. In other words, the use of the CMPU-Ht as a method to assess athletes' potential or progress needs further investigation and determination of a method to obtain CMPU vertical displacements values.

CHAPTER 3

RELIABILITY OF COUNTERMOVEMENT PUSH-UP HEIGHT DERIVED WITH A JUST JUMP MAT

Upper-body extensor muscle performance is essential to a number of sport skills including: shot put, football lineman block, and boxing punches. Performance assessment of high school football players by Williford, Kirkpatrick, Scharff-Olson, Blessing, and Wang (1994) demonstrated that lineman had greater bench press (upper-body extensor muscle) performance than other positions. Additionally, Gordon, Moir, Davis, Witmer, and Cummings (2009) examined the relationship of different performance tests and their relationship to golf club head speed, which resulted in chest strength having the highest correlation ($r = 0.69$). The importance of upper-body extensor muscle performance has also been incorporated in the assessment of boxer's ability to produce force. Therefore, strength and conditioning coaches working with athletes to enhance extensor performance need a test that yields reliable measures of the performance of upper-body extensor muscles to evaluate the efficacy of training programs. If the test is not reliable coaches will not be able to determine if changes in arm performance are occurring as a response to training or if the changes are just random measurement errors. Laboratory tests, such as bench press throws are available for obtaining valid and reliable measures

of upper-body extensor performance (Cronin & Owen, 2004; Cronin et al., 2001; Falvo et al., 2006); but because of cost and time limitations, laboratory tests are not accessible or appropriate to most coaches. A practical upper-body extensor performance test is needed.

The current study's examination of force-time variables associated with the countermovement push-up (CMPU) provides insight into a possible strategy for a practical upper-body extensor performance test. Using three dimension motion analyses and a force platform, the current study noted that the CMPU vertical displacement (CMPU-Ht) was related to peak force and peak power, suggesting that if an inexpensive technique for assessing of CMPU-Ht could be identified, CMPU-Ht might serve as a measure of upper body extensor performance.

The Just Jump® mat is a relatively inexpensive (\approx \$500) tool that uses flight-time to predict countermovement vertical jump height, but the use of the Just Jump® mat has not been examined as a tool for measuring CMPU-Ht. The current study investigated the reliability of the measurements of CMPU-Ht assessed with a Just Jump® mat as a practical method for assessing upper-body extensor power.

Methods

Experimental Approach to the Problem

A randomized, test-retest design was used to examine the day-to-day stability of CMPU-Ht measurements derived with a Just Jump® mat. The 15 volunteer participants reported to the laboratory on three separate occasions. The first laboratory session served

as an opportunity for collecting demographic information and familiarizing the participants with the CMPU protocol. During the second (TT1) and third (TT2) laboratory sessions, the test-retest of achieved CMPU-Hts were compared to provide insight into the reliability of Just Jump® mat derived CMPU-Hts.

Participants

All participants in this investigation completed a consent form and were informed of the requirements of the study, which was conducted with the approval of the University of Utah Institutional Review Board. Fifteen participants (13 = males and 2 = females); (mean \pm SD) age = 26.87 ± 2.72 years, height = 178.83 ± 7.92 cm, body mass = 84.85 ± 15.53 kg, and bodyfat percent = 17.31 ± 6.20 % were recruited from the University of Utah and the Department of Exercise and Sport Science. Participants were classified as trained with a mean training frequency of 3.47 ± 0.99 days per week and a mean training time of 57 ± 15.21 minutes per training session. Eleven of the participants were engaged in strength training programs. Four of the participants did not engage in strength training on a regular basis, but they were aerobically exercising, playing basketball, or engaging in muscular endurance training. Participants who were previously diagnosed by a physician with any musculoskeletal disease or soft tissue injury that might impair their ability to execute a CMPU were excluded from the study.

Initial Laboratory Session

A schematic of the study timeline is presented Table 2.1. For the initial laboratory session the following descriptive data were collected:

1. *Body mass.* Participant's BM was obtained on an IQ plus 355 weight indicator (Rice Lake Weighing Systems, Inc., Rice Lake, WI) and recorded to 100th kilograms.
2. *Height.* HT was measured barefoot with a wall mounted ruler in centimeters (cm) and recorded to the nearest millimeter.
3. *Body composition.* Body-fat percentage (BF%) was calculated using a 7-site formula (American College of Sports Medicine, 2006). All seven SKF sites were measured by the lead investigator with 20 years of experience using the Lange Caliper (Beta Technology, Santa Cruz, CA).

In addition to collecting demographic information, during the initial laboratory session time was devoted to familiarizing the participants with the CM push-up. Timed push-up (PU) tests have typically been used to determine a person's upper-body muscular endurance (Cronin & Owen, 2004; Hrysomallis & Kidgell, 2001); however, utilization of the timed PU seems to be a poor method for assessing strength and power (Cronin & Owen, 2004). One element of the timed PU test that detracts from its utility as a measure of muscular strength is that PUs require the upper-body muscles to move approximately 60% of a person's body mass (Cogley et al., 2005; Hrysomallis & Kidgell, 2001). The ability to move less than 100% of a person's body mass makes the timed PU test a muscular endurance test rather than a muscular strength test. Cronin et al. (2001) and Falvo et al. (2006) have reported that the addition of a CM to the bench press significantly increased the force-time characteristics of the bench press. Based on the findings of Cronin et al. (2001) and Falvo et al. (2006), a CM was added to the PU, creating a CMPU.

Because the CMPU may be a novel exercise, during the initial laboratory session the participants were introduced to the CMPU and allowed to practice the movement. Prior to executing the CMPU, the participants were instructed to select a comfortable hand position. Self-selected hand position was used because hand position has been shown to influence the muscle activity of the upper-body muscles (Cogley et al., 2005; Gouvali & Boudolos, 2005). If the hand position is too narrow, higher muscle electromyographic activity (EMG) occurs, but a lower maximal vertical force (F_z) is observed than when a wider hand position is used (Cogley et al., 2005; Gouvali & Boudolos, 2005). Self-selection of hand position for performing the CMPU allowed participants to be in a position that they deemed to be the optimal for the individual participant. As a strategy for improving consistency between trials, the self-selected hand position width was recorded as centimeters deviation from the center point of a template. This hand position was replicated for all CMPUs completed for the study.

Following the recording of hand position distances, participants performed an upper-body dynamic warm-up (DWU) (Table 2.2) and then they performed 5 CMPUs. The DWU utilized exercises that prepared the musculature from the pelvic region up to the shoulder joint muscles. More repetitions were taken if the participant wanted more practice. Each CMPU was initiated with the hands on the force plate, elbows fully extended, shoulders flexed, torso and legs extended, and feet together with toes and balls of feet in contact with the ground. Participants then rapidly lowered their chest, but just before contact with the force platform, they quickly changed directions pushing their body into the air until the elbows were fully extended and hands broke contact with the force platform (Hrysomallis & Kidgell, 2001).

Test Trials

All TT's took place 48-72 hours apart to minimize the influence of fatigue of the participants and accommodate weekend, school, or work schedules. Each participant's BM was measured prior to completion of the DWU.

After the DWU, participants performed the CMPU, using their previously determined self-selected hand position, on a on a Just Jump® mat to obtain CMPU-Ht. Participants were instructed to pause prior to each CMPU repetition (Jo et al., 2010) to allow for their hands to be reset in the proper position for the completion of the next of the five repetitions. A repetition was not counted if the participant was unable to propel their hands off the Just Jump® mat. The amount of vertical displacement derived with the Just Jump® mat for each of the five CMPU repetitions was recorded. The same procedures were followed for TT2. The three highest repetitions for both TT1 and TT2 were used for analysis.

Statistical Analysis

Means, and standard deviations were calculated for the highest CMPU-Ht recorded during both TT1 and TT2. A repeated measure ANOVA was used to examine the stability between the TT1 and TT2 CMPU-Ht repetitions. An intraclass correlation coefficient (ICC) and a Pearson Product Moment Correlation (PPM) were also used to examine test-retest reliability of the TT1 and TT2 CPMU-Hts (Atkinson & Nevill, 1998; Shim et al., 2001). Lastly a Bland Altman plot was used to examine the level of agreement between the TT1 and TT2 mean CMPU-Hts (Atkinson & Nevill, 1998). An a

priori of $\alpha = 0.05$ was used for all analyses and all statistical analyses were performed on PASW Statistics 18.0 (Formerly SPSS; IBM Inc., Chicago, IL).

Results

The descriptive statistics for the three CMPU repetitions for TT1 and TT2 are presented in Table 3.1 and Figure 3.1. Repeated measures ANOVAs were used to examine the stability of the TT1 and TT2 CMPU-Hts. There were no significant differences between the peak CMPU-Ht means (29.07 ± 8.67 cm and 29.58 ± 9.31 cm, respectively) ($p = 0.77$). The Pearson Product Moment correlation for the peak TT1 and TT2 CMPU-Hts was $r = 0.74$ ($p = 0.002$). ICC, standard error of the measurement (SEM), and coefficient of variation (CV%) of between days for the JJ derived peak CMPU-HT measurements are presented in Table 3.2. A Bland-Altman plot was used to visually compare the level of agreement between TT1 and TT2 peak CMPU-Ht means (Figure 3.2) (Atkinson & Nevill, 1998). Visual observation of the Bland-Altman graph shows one point outside of the 95% limits of agreement.

Table 3.1: JJ CMPU-Ht Descriptive Statistics.

	TT1			TT2		
Repetition	1	2	3	1	2	3
Mean (cm)	27.35	27.97	26.77	28.24	28.50	27.96
SD (\pm)	7.89	8.59	8.77	8.84	9.39	9.70

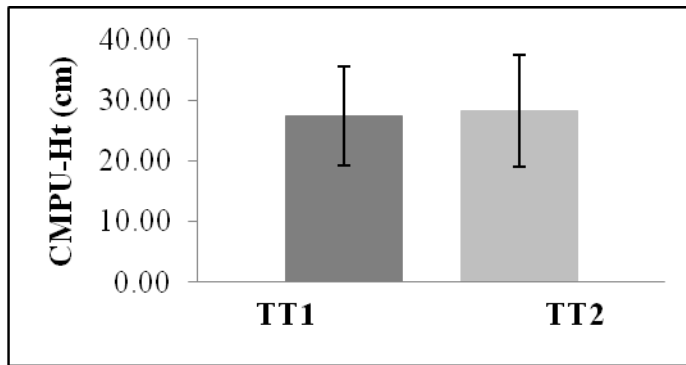


Figure 3.1: Just-Jump® mat Peak CMPU-Ht. *Significant difference between TT1 and TT2 ($p < 0.05$)

Table 3.2: Test-retest reliability of the JJ CMPU data.

JJ CMPU-Ht	ICC (95% CI)	Systematic Bias (cm)	Random Error (cm)	CV%	SEM
Peak	0.84 (.53 - .95)	-0.51	± 1.72	12%	3.38

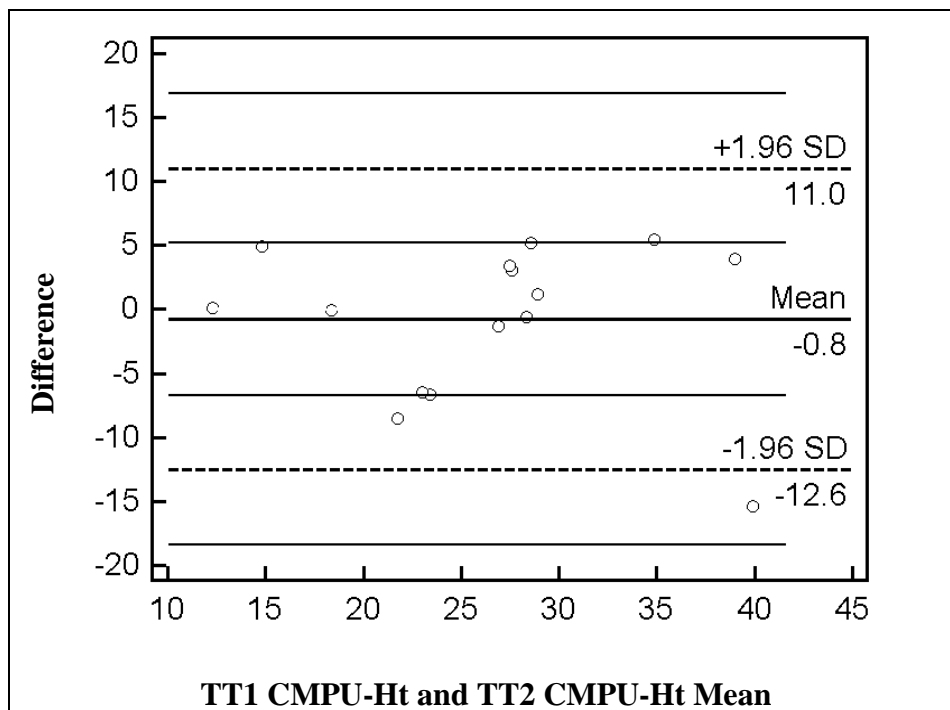


Figure 3.2: Bland-Altman Scatterplot

Discussion

Previous studies have investigated the reliability of various upper-body extensor muscle performance tests involving the movement or displacement of some form of equipment (Clemons et al., 2010; Cronin & Owen, 2004; Cronin et al. 2001; Vossen, Kramer, Burke, and Vossen, 2000). Instead of an external load, the current study utilized body mass as the load and a JJ predicted C MPU-Ht was used to assess upper-body extensor muscle performance. A number of different test-retest analyses were used to examine the measurement error associated with the JJ C MPU-Hts. The results of these analyses were mixed. The ICC alpha value of 0.84 indicated moderate (Atkinson & Nevill, 1998) relative reliability for JJ derived predictions of C MPU-Ht.

Of the test-retest analyses examining absolute reliability, the Bland-Altman plot provided evidence of agreement between the TT1 and TT2 peak C MPU-Ht values. The lack of a significant difference between the TT1 and TT2 peak C MPU-Ht values was consistent with the level of agreement illustrated in the Bland-Altman plot. In addition, the systematic bias (-0.51 cm) and random error (1.72 cm) were low; however, the CV% of 12% and the very large SEM of 3.38 suggest poor absolute reliability.

The high coefficient of variation (CV% >10%) in the current study could be the result of a possible learning effect among some of the participants between TT1 and TT2. The systematic bias, indicating that the TT2 peak C MPU-Ht was higher than the TT1 peak C MPU-Ht, is further support of a learning effect. Future, research needs to be completed to determine the optimal number of repetitions necessary to remove systematic bias due to learning.

It is unlikely that hand position for the CMPU contributed to the measurement error in this study because an individually determined template was used to ensure that a consistent hand position was used for each participant. Each participant's hand position template was a self-selected hand position based on the premise that a person will elect a hand position that will permit them to achieve the most optimal vertical body displacement. Previous research has demonstrated that hand position can influence muscle activity of the upper-body musculature (Atkinson & Nevill, 2001; Cohen et al., 2003). Future research on the CMPU would benefit from assessing muscle activity (EMG) of the upper-body musculature associated with various force-time variables during the execution of a CMPU using different hand positions, different body positions (e.g., feet elevated), and external loading for the most appropriate assessment of the CMPU.

Application

Previous research indicates that the CMPU does require the participant to use the upper-body musculature to rapidly exert force against the floor or ground to propel the upper-body into the air. Consequently strength and conditioning coaches who want to develop the ability of their athletes to use the upper-body extensor muscles to rapidly exert force may continue to use the CMPU as a training exercise. The current study; however, suggests that JJ derived CMPU-Ht values have too much SEM to be used to reliably assess the effects of training programs or to evaluate the strengths and weaknesses of individual athletes.

CHAPTER 4

VALIDITY OF COUNTERMOVEMENT PUSH-UP HEIGHT DERIVED WITH A JUST JUMP MAT

Upper-body muscular extensor performance is essential to a number of sport skills including: shot put or a jab in boxing. Therefore, strength and conditioning coaches working with athletes to enhance performance need a test that yields valid measures of upper-body extensor performance to evaluate the efficacy of training programs as well as to assess the strengths and weaknesses of individual athletes. Laboratory tests, such as bench press throws or isometric bench pressing are available for obtaining valid and reliable measures of upper-body extensor performance; but because of cost and time limitations, laboratory tests are not available to most strength and conditioning coaches. A practical upper-body extensor performance test is needed.

The current study examining force-time variables associated with the countermovement push-up (CMPU) provides insight into a possible strategy for a practical upper-body extensor performance test. Using simultaneous three dimension motion analysis and force platform analysis, the force-time variable study noted that CMPU vertical displacement (CMPU-Ht) was related to peak force and peak power, suggesting that if an inexpensive technique for assessing of CMPU-Ht could be identified, CMPU-Ht might serve as a measure of upper body extensor performance.

The Just Jump mat is a relatively inexpensive (\approx \$500) tool that has been used to predict countermovement vertical jump height from flight time, but the use of the Just Jump mat has not been examined as a tool for predicting CMPU-Ht. The current study investigated the validity of the predictions of CMPU-Ht assessed with a Just Jump® mat as a practical method for assessing upper-body extensor muscle performance.

Methods

Design and Approach to the Problem

This study was designed to use several approaches to examine the CMPU-Ht derived from a Just Jump mat as a valid measure of upper body extensor performance. The 15 volunteer participants reported to the laboratory on three separate occasions. The first laboratory session served as an opportunity for collecting demographic information and familiarizing the participants with the CMPU protocol, and collecting performance data on 1RM bench press strength and 1 minute timed push-ups. During the second (TT1) and third (TT2) laboratory sessions, after identification of the anatomical landmarks for reflective markers occurred, the CMPU was simultaneously examined with three-dimensional motion analysis and the JJ mat. The CMPU was also simultaneously examined with three-dimensional motion analysis and a force platform. Examination of criterion validity was approached by using three dimensional motion analysis to measure CMPU-Ht for comparison with the JJ CMPU-Ht. Evidence of construct validity was sought by comparing the force platform derived CMPU force-velocity variables of peak power (PP), peak force (PF), impulse (IMP), and peak rate of force development (PRFD) with JJ CMPU-Ht. Convergent validity was examined by comparing JJ CMPU-Ht and 1

RM bench press strength, whereas divergent validity was assessed by comparing JJ CMPU-Ht and 1 minute timed push-ups score. The study received ethics approval from the University of Utah, Institutional Review Board.

Participants

All participants in this investigation completed a consent form and were informed of the requirements of the study. Fifteen participants (13 = males and 2 = females); (mean \pm SD) age = 26.87 ± 2.72 years, height = 178.83 ± 7.92 cm, body mass = 84.85 ± 15.53 kg, and bodyfat percent = 17.31 ± 6.20 % were recruited from the University of Utah and the Department of Exercise and Sport Science. Participants were classified as trained with a mean training frequency of 3.47 ± 0.99 days per week and a mean training time of 57 ± 15.21 minutes per training session. Eleven of the participants were engaged in strength training programs. Four of the participants did not engage in strength training on a regular basis, but they were aerobically exercising, playing basketball, or engaging in muscular endurance training. Participants who were previously diagnosed by a physician with any musculoskeletal disease or soft tissue injury that might impair their ability to execute a CMPU were excluded from the study.

Initial Laboratory Session

A schematic of the study timeline is presented Table 2.1. For the initial laboratory session the following descriptive data were collected:

Body mass. Participant's BM was obtained on an IQ plus 355 weight indicator (Rice Lake Weighing Systems, Inc., Rice Lake, WI) and recorded to 0.01 kg.

Height. HT was measured barefoot with a wall mounted ruler in centimeters (cm) and recorded to the nearest millimeter.

Body composition. Body-fat percentage (BF%) was calculated using a 7-site formula (1) . All seven SKF sites were measured by the lead investigator with 20 years of experience using the Lange Caliper (Beta Technology, Santa Cruz, CA).

Participant Upper-body Performance Testing

In preparation for the upper-body performance testing and familiarization with the C MPU, a dynamic warm-up (see Table 2.2) was completed. The first upper-body performance test was a 1-repetition maximum (1-RM) bench press (BPR) on a Paramount Selectorized machine Tomchuk (2011). This test was used to assess participant's upper-body strength. Participants were asked to identify their 1-RM BPR, to serve as a target weight for the testing process. To begin the process the participant was instructed to use a wide hand grip (wider than shoulder) and the grip width was recorded to ensure consistency between sets. Beginning with either 18.60 or 23.59 kg a 5 repetition warm-up was completed. Using increments of 2.5 to 10 kg, 3 to 5 sets of 1 repetition were used to reach the participant's 1-RM BMR. If a participant was able to lift the entire weight stack on the BPR machine, they performed as many repetitions as possible, which were then used to estimate their 1-RM using the Brzycki (1993) formula. Following each of the BPR sets, participants had a 2 minute rest to provide recovery time between sets.

Participants performed the machine BPR starting with an ascending phase until the elbows were fully extended for at least 1 second. For the descending phase the participant was instructed to slowly lower the weight stack until it was resting (at least 1

second) at the starting position. A machine BPR was used as a safety precaution because some of the participants were unfamiliar with weight training.

A 5-minute recovery followed the 1-RM BPR to allow for recovery prior to the 1-minute upper-body muscular endurance push-up (PU) test (Tomchuk, 2011). Participants started the PU test with elbows fully extended, shoulders flexed, torso and legs straight, and feet together with toes and balls of feet in contact with the ground. The participant then lowered themselves until the upper arms were parallel to the floor or the chest came in contact with the floor. The participant then changed directions of the PU, pushing their body upward until the elbows were fully extended and the body had returned to the start position. The PU was performed for as many repetitions as possible within a 1 minute time period.

CMPU Practice

Timed push-up (PU) tests have typically been used to determine a person's upper-body muscular endurance (Ferreira et al., 2010; Kilduff et al., 2008); however, utilization of the timed PU seems to be a poor method for assessing force-time performance (Ferreira et al., 2010). One element of the timed PU test that detracts from its utility as a measure of muscular strength is that a PU requires the upper-body muscles to move only 60% of a person's body mass (Cronin & Owen, 2004; Enoka, 1988). The ability to move less than 100% of a person's body mass makes the timed PU test a muscular endurance test rather than a muscular strength test. Cronin et al. (2001) and Falvo et al. (2006) have reported that the addition of a CM to the bench press significantly increased the force-time characteristics of the bench press. Using the findings of Cronin et al. (2001) and

Falvo et al. (2006), a CM was added to the PU, creating a CMPU, an upper-body performance exercise.

Because the CMPU may be a novel exercise, during the initial laboratory session the participants were introduced to the CMPU and allowed to practice the movement. Prior to executing the CMPU, the participants were instructed to select a comfortable hand position. Self-selected hand position was used because hand position has been shown to influence muscle activity of the upper-body muscles (Gouvali & Boudolos, 2005). If the hand position is too narrow, higher muscle electromyographic activity (EMG) occurs, but a lower maximal vertical force (F_z) is observed than when a wider hand position is used (Caruso et al., 2010; Enoka, 1988). Self-selection of hand position for performing the CMPU allowed participants to be in a position that they deemed to be the optimal for the individual participant. As a strategy for improving consistency between trials, the self-selected hand position width was recorded as centimeters deviation from the center point of a template. This hand position was replicated for all CMPUs completed for the study.

Following the recording of hand position distances, participants performed 5 CMPUs. More practice repetitions were taken if the participant wanted more practice. Each CMPU was initiated with the hands on the force plate, elbows fully extended, shoulders flexed, torso and legs extended, and feet together with toes and balls of feet in contact with the ground. Participants then rapidly lowered their chest, but just before contact with the force platform, they quickly changed directions pushing their body into the air until the elbows were fully extended and hands broke contact with the force platform (Cronin & Owen, 2004; Gouvali & Boudolos, 2005).

Test Trials

All TT's took place 48-72 hours apart to minimize the influence of fatigue and accommodate weekend, school, or work schedules. Participants had their BM obtained prior to each TT. For TT1, the reflective markers necessary for motion capture analysis (MA) were positioned. The following bony landmarks were used: 3rd metacarpal, radial and ulnar styloid, medial and lateral epicondyles, acromion process, medial superior scapulae spine, medial inferior scapulae apex, right off-set marker and cervical 7-thoracic 1 spinous process. The reference points for the reflective markers were maintained throughout the study by placing an indelible ink mark over each site. A 10 Camera Raptor-E Digital Real Time Camera System (Motion Analysis Corporation, Santa Rosa, CA) was used to measure CMPU-Ht using the reflective markers. Kinematic data were collected at a sampling rate of 120 Hz and raw data were first processed to eliminate any noise artifact, followed by a low pass filtered at 6 Hz using a 2nd order zero lag Butterworth digital filter.

When the reflective markers were in place, the DWU was completed. Participants then performed a CMPU with their hands positioned on a BP400600 (2000 lb capacity) force platform (FP) (Advanced Mechanical Technology, Inc., Watertown, MA), which was used to measure PP, PF, IMP, and PRFD. Kinetic data were sampled at 400 Hz for the entire completion of all CMPU repetitions. Participants CMPU-Ht was determined by measuring, to the nearest 0.01 cm, the displacement of C7-T1 reflective marker through motion analysis. The TT1 CMPU and TT2 CMPU with the highest PF, was reported as N (Newton), were used to obtain the PRFD, PP, and CMPU-Ht values. Only FP data during the concentric phase of the CMPU were analyzed. PRFD was determined

by using the greatest gradient of 10 consecutive data points that occurred in the first 50 ms of the concentric phase of the CMPU and was reported as $N \cdot s^{-1}$ (Newtons per second; see Figure 2.1). PP was determined by taking the product of PF and CMPU-Ht, and dividing the product by the time from PF to point of take-off ($P = (f \times d) / t$) and was reported as W (Watts). IMP was calculated by taking the average force from start of concentric action to its completion then multiplying by the time required for the action to occur ($IMP = F_{avg} \times t$) and was reported as $N \cdot s$ (Newton second).

A 2' minute rest followed the CMPUs on the force platform before the completion of 5 CMPUs using self-selected hand position on a Just Jump® mat. Again, participants were instructed to pause prior to each CMPU repetition (Jo et al., 2010) to allow for their hands to be reset in the proper position. The amount of vertical displacement derived from the Just Jump® mat for of the 5 CMPU repetitions was recorded. The same procedures were followed for TT2.

Statistical Analysis

The values associated with the peak MA CMPU-Hts from the two test sessions were used for calculation of descriptive statistics. Examination of validity evidence used the mean of the values associated with the two test sessions, therefore the mean of the two motion capture peak CMPU-Hts was used as the criterion measure for JJ CMPU-Ht. Evidence of construct validity was obtained by comparing the mean of the force platform derived CMPU force-velocity variables of PP and PF with the mean JJ CMPU-Ht. Convergent validity was examined by comparing the mean of the JJ peak CMPU-Ht and 1 RM bench press strength, whereas divergent validity was assessed by comparing the

mean of the JJ peak CMPU-Ht and 1 minute timed push-ups score. All statistical analyses were performed on PASW Statistics 18.0 (Formerly SPSS; IBM Inc., Chicago, IL).

Results

One participant was dropped from the statistical analysis of the JJ CMPU-Ht and MA CMPU-Ht comparison because their MA values were not obtained.

Criterion Measure Reliability

The means for the TT1 and TT2 peak MACMPU-Ht were 25.15 ± 8.18 cm and 26.34 ± 7.72 cm respectively. The intraclass correlation coefficient (ICC), coefficient of variation (CV%) and standard error of measurement (SEM) can also be seen in Table 4.1. The MA CMPU-Hts were not significantly different. The ICC was high, the CV% was 10% and the SEM was 2.16 supporting the reliability of the criterion measure, the motion analysis system. SEM values reported below 5.00 cm and CVs at or below 10% for MA CMPU-Ht suggest internal consistency (Atkinson & Nevill, 1998).

Validity Analyses

Because there was not a significant difference between the TT1 and TT2 CMPU-Ht values, the two were averaged for further analysis. To examine the criterion validity the mean of the MA peak CMPU-Hts was compared to the mean of the JJ peak CPU-Hts and a significant difference was observed. The JJ Peak CMPU-Ht (29.58 ± 8.61 cm) was significantly higher than the JJ peak CMPU-Ht (25.75 ± 7.64 cm). Figure 4.1 portrays a

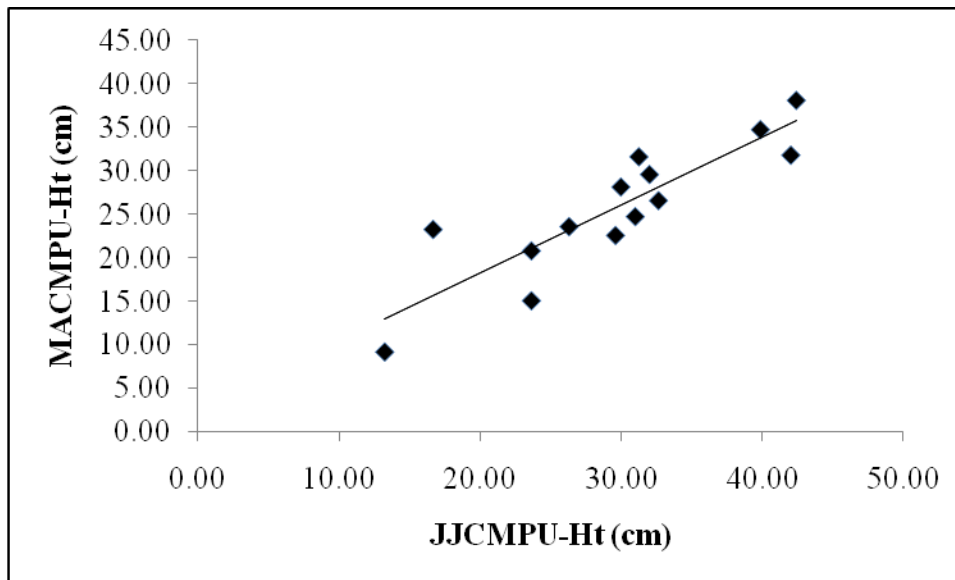


Figure 4.1: Scatter plot of TT1 JJ and MA CPMU-Hts

scatter plot between the MA mean peak CPMU-Ht and the JJ mean peak CPMU-Ht. The Pearson correlation associated the relationship in Figure 4.1 was 0.88 ($p = 0.000$)

Construct validity was examined by comparing the JJ mean peak CPMU-Hts with PF and PP. The associated correlation coefficients can be seen in Table 4.2.

The correlation coefficients used to examine convergent validity by comparing mean peak JJ CPMU-Hts with BPR are also in Table 4.2. Figure 4.2 presents the scatterplot of mean peak JJ CPMU-Ht and BPR.

Divergent validity was examined by comparing the JJ mean peak CPMU-Ht with PU. The correlation between these two variables was $r = 0.51(p > 0.05)$. Figure 4.3 represents the scatterplot for JJ peak mean CPMU-Ht and PU.

Table 4.1: Test-retest reliability and coefficient of variation for MA CMPU-Ht. (* $p < 0.05$)

CMPU-Ht	TT1	TT2	ICC	CV%	SEM
Motion Analysis	25.15 ± 8.18	26.34 ± 7.72	0.92	10%	2.16

Table 4.2: Correlation of JJ CMPU-Ht with force-velocity variables and performance variables. *(Significance < 0.05)

CMPU-Ht	MACMPU	PP	PF	BPR	PU
Just Jump	$r = 0.88^*$	$r = 0.72^*$	$r = 0.64^*$	$r = 0.71^*$	$r = 0.51$

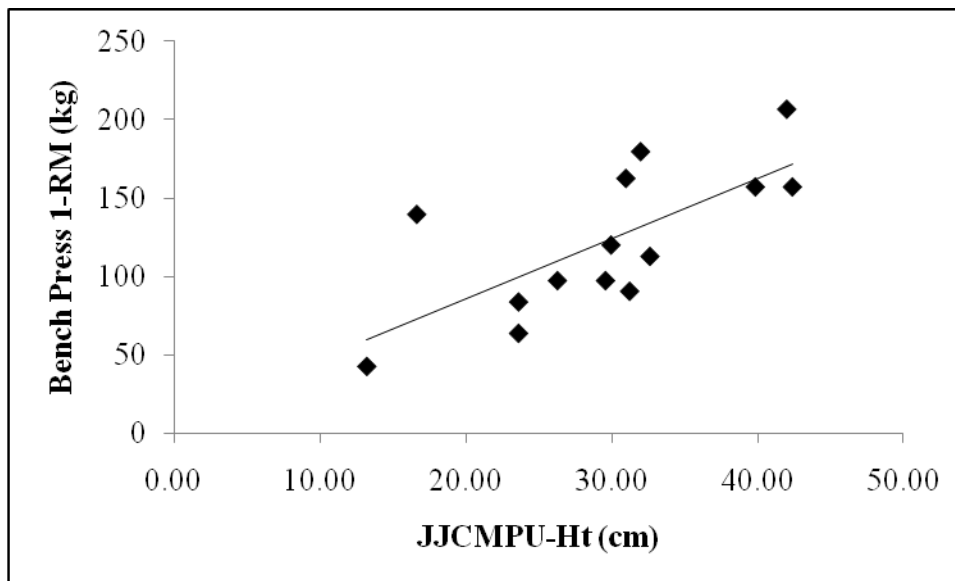


Figure 4.2: Scatter-plot of BPR and JJ CMPU-Hts Grand Means

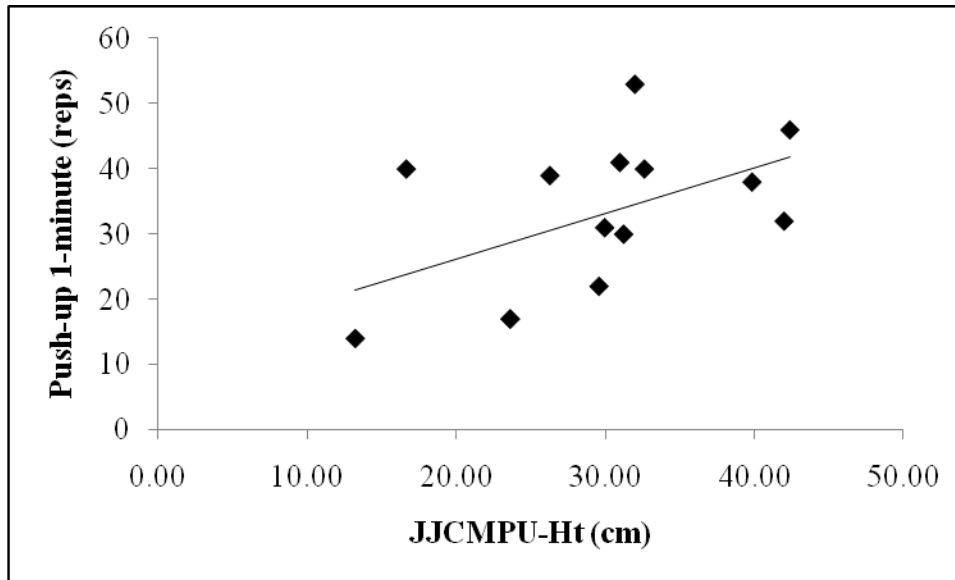


Figure 4.3: Scatter-plot of PU test and JJ CPMU-Ht means

Discussion

The results of the current study provide modest evidence in support of the validity of Just Jump® mat measures of CPMU-Ht. Convergent and construct validity analysis was based on the previous work by Tudor-Locke, Williams, Reis, and Pluto (2000) and (2004). The PPM correlation between JJ and MA CPMU-Ht demonstrated a significant relationship of $r = 0.88$ ($p = 0.000$), indicating high relative validity in comparison to the criterion method of MA. However, a statistically significant ($p = 0.004$) difference was observed between JJCMPU-Ht and MACMPU-Ht, indicating poor accuracy. On average, the JJ overestimated (> 3.00 cm) body displacement of a CPMU in comparison to motion analysis displacement (see Table 4.3). The simultaneous measurement of CPMU-Ht with MA exhibited high relative and absolute reliability (see Table 4.2). Perhaps variability in participant body mass, a factor that would not have influenced the MA CPMU-Ht measurements, was the source of measurement error.

Table 4.3: Test-retest reliability and coefficient of variation for JJ CMPU-Ht.

CMPU-Ht	TT1	TT2	ICC	CV	SEM
Just Jump	29.52 ± 8.82	29.64 ± 9.66	0.86	11%	3.22

Convergent validity was examined by comparing the mean Peak JJ CMPU-ht to the BPR. The PPM demonstrated that there was a large and significant relationship between mean ($r = 0.71$, $p = 0.004$) JJ CMPU-Ht and BPR, providing some evidence of convergent validity for JJ CMPU-Ht. Further investigation is needed to ascertain if convergent validity exists between the CMPU and other upper-body extensor power tests such as the medicine ball chest throw or bench throw. Additionally, there is a need for a comparison of the CMPU to varying muscular actions such as isometric and isokinetic bench presses. There may be a large relationship of the CMPU performance to other muscular actions that may support the validity of JJ CMPU-Ht as a measurement of upper-body extensor muscular power.

The current study used the 1-minute PU to investigate divergent validity of the JJ CMPU-Ht. There was a nonsignificant ($p = 0.06$) but moderate PPM ($r > 0.50$) between JJ CMPU-Ht and PU. The low relationship is not surprising as the PU assesses upper-body muscular endurance, which is the ability of respective muscles to perform repetitive muscular actions against submaximal forces.

The overall PPM results for criterion, construct and convergent validity suggests that the JJ may have some validity ($r > 0.70$). However, the accuracy of the JJ obtaining vertical displacement of person from the execution of a CMPU is low. The utilization of

the JJ to accurately assess C MPU performance with the goal of determining a person's force-time variables needs further investigation. Furthermore, with only the force-time variable of PP demonstrating validity ($r > 0.70$) to the JJ-C MPU-Ht the use of the JJ may not be an appropriate tool to assess all upper-body extensor muscle performance.

Practical Application

Although the MA data suggest that the C MPU has potential as an upper-body extensor muscle performance test, JJ seems to be a adequate tool for assessing C MPU-Ht. Additional investigation is needed to identify a tool that results in reliable and valid measurement of C MPU-Ht. Based upon the force-time variable observed with MA of the C MPU, strength and conditioning coaches may continue to use the C MPU as an exercise to train the force producing abilities of the upper body extensor musculature.

CHAPTER 5

FINDINGS, CONCLUSION, AND RECOMMENDATIONS FOR FUTURE RESEARCH

Although an upper-body extensor muscle performance “Gold Standard” test has not been established (Clemons et al., 2010; Cronin & Owen., 2004; Shim et al., 2001; Wilson et al., 1994), a number of laboratory-based bench press tests have been used. Because of requirements for expensive instrumentation and significant administration time requirements, laboratory-based tests are not realistic for use by strength and conditioning coaches. Furthermore, the development of upper-body extensor muscle performance tests requires the analyses of both reliability and validity (Gillespie & Keenum, 1987; Shim et al., 2001).

The most popular field-based upper-body extensor performance based test is the medicine ball throw. However, a set mass of a medicine ball and starting position (seated with back at 45° or 90°) does not currently exist for the medicine ball throw increasing the variability in the results. The current studies investigated the use of a CMPU as a method to evaluate upper-body power. The decision to use the CMPU was based on comments by Shim et al., (2001) which stated, “...to avoid the confounding influence of motor learning, a field test should not require much practice, but consist of basic motor skills.” (p. 193) The push-up qualifies as a well-known exercise and it is similar to the

CM jump test that is used to evaluate lower-body performance by measuring vertical displacement resulting from the CMJ.

The use of CMPU-Ht as a measure of upper body extensor muscle performance was approached by using simultaneous MA and FP data to describe the force-time variables associated with the CMPU. The FP CMPU force-time associated with PF (477.74 ± 179.73 N) were: $IMP = 198.40 \pm 77.99$ N·s; $PRFD = 6,254.93 \pm 4409.89$ N·s⁻¹. The simultaneously observed MA derived CMPU-HT was 24.64 ± 7.01 cm. PP was derived by using both MA and FP data and was equal to 329.15 ± 178.06 W. Only the PF and PP were significantly related to CMPU-Ht. The significant relationship ($r = 0.70$) between CMPU-Ht and PF suggested that further research was warranted to determine if CMPU-Ht could be used to assess upper-body extensor muscle performance by measuring CMPU-Ht.

The reliability of the measurements of CMPU-Ht assessed with a JJ as a practical method for assessing upper-body extensor muscle performance demonstrated good relative reliability but poor absolute reliability. Relative reliability was displayed by no significant differences between the peak CMPU-Ht means (29.07 ± 8.67 cm and 29.58 ± 9.31 cm, respectively) ($p = 0.77$) along with a large significant relationship $r = 0.74$ ($p = 0.002$). The high CV of 12% and the very large SEM of 3.38 suggest poor absolute reliability of the JJ to assess CMPU height signifying that a more precise method needs investigating. Although there is a suggestion of reliability, an unacceptable large measurement error exists that would make tracking changes in upper-body extensor muscle performance.

The validity of the predictions of CMPU-Ht assessed with a JJ as a practical method for assessing upper-body extensor muscle performance were examined through construct, convergent, divergent, and criterion validity analyses. The construct validity was approached by examining the relationship of JJ mean peak CMPU-Hts with PF and PP, which had a correlation of $r = 0.64$ and $r = 0.72$, respectively. Convergent and divergent validity was approached by examining the relationship of between mean peak JJ CMPU-Hts with BPR and PU. The correlational results of convergent validity was $r = 0.71$ whereas divergent validity of PU was $r = 0.51$ providing some evidence of convergent and divergent validity but further investigation is needed with other upper-body performance test (e.g., bench throw, YMCA bench press test). Criterion validity was observed between JJCMPU-Ht and MACMPU-Ht with a large $r = 0.88$ but had poor accuracy with a statistically significant ($p = 0.004$) difference between the two testing methods. The MA data suggests that the CMPU has potential as an upper-body extensor muscle performance test. However, JJ reliability appears to be good but not great and may not be an accurate tool for assessing CMPU-Ht. Further investigation is needed to determine if the JJ there is a more reliable and valid tool to assess CMPU performance.

Limitations and Future Research

Numerous studies have limited the comparison performance values to only muscular strength (1-RM bench press) and muscular endurance (1-minute push-up) tests (Gouvali & Boudolos, 2005; Invergo, Ball, & Looney, 1991). Although female strength values have been categorized with lower values or percentiles among other muscular performance tests compared to males (Hoffman, 2006; Morrow Jr., Jackson, Disch, &

Mood, 2000), the ability to explosively move a participant's body weight is necessary when performing a CMPU. The CMPU required the participant to displace approximately 66% of their bodyweight (Gouvali & Boudolos, 2005), thus lower force-time ability of the upper-body muscular extensors for any of the participants may have limited vertical displacement of the body. The participants in the current study all were capable of displacement during the execution of a CMPU. Therefore, the inclusion of female participants in future studies may be used as a separate group to assess not only CMPU force-time variables but also the reliability and validity of the JJ and similar devices.

In regards to the participant selection within the studies, the majority of the participants were regularly engaged in an exercise plan but they however could not be classified as athletes. The current participants can only be generalized to person's who train on a regular basis (frequency = 3.47 ± 0.99 days; training time = 57 ± 15.21 minutes) with the mean age of 26.87 ± 2.72 years. Furthermore, the participants' current training emphasis was recorded but the exact exercises, methods, and principles implemented by the participants were not ascertained. However, 11 of the participants were engaged in a regular strength or aerobic training plan whereas all of the participants reported being actively engaged in a regular exercise program. The exact training variables of each participant may demonstrate an influence on the participants' CMPU performance and should be considered in future studies. Additionally, sleeping and dietary recall were not evaluated during the course of the study as it was deemed not to have an impact on the results of the study. Lastly, all participants were instructed to maintain their current

exercise plan, sleep, and diet patterns during the testing period to minimize any influence on C MPU performance.

The training status of the participants is one area for future studies to examine if there is a difference between strength, aerobic, muscular endurance, and speed dominant athletes. Training status of the individuals can have influence on C MPU performance though the amount of differences between the categories needs to be examined. Harrison et al. (2004) demonstrated that sprinters had greater performance in stretch-shortening cycle performance compared to endurance trained individuals. Chiu et al. (2003) demonstrated that athletically trained participants can have a greater increase to performance from a potentiating effect than recreationally trained participants. Participant selection in the future should utilize person's who are not regularly participating in an exercise to evaluate the performance capabilities of untrained subjects. Additionally, a comparison of varying athletic populations such as explosive strength athletes (i.e., shot putter) and endurance athletes (i.e., cross-country skier) would allow for upper-body muscular ability of differing sports. These data could lead to further investigation of which sport may benefit from the addition of the C MPU to their training plan.

Another possible variable that may have influenced performance during the study was a fatiguing effect that may have influenced C MPU performance. However, based on the pattern of each C MPU-Ht trial during each TT a pattern can be observed that the 2nd and 3rd repetitions had the highest values in comparison to the 1st, 4th and 5th repetitions. The suggestion that a fatiguing influence is possible, it would be prudent for strength and conditioning coaches to have athletes perform at least a minimum three attempts if using

the CMPU-Ht to assess upper-body muscle extensor power. Furthermore, a greater CMPU-Ht was observed in TT2 than in TT1, which would suggest a possible learning effect. However, a 2-tailed t-test of CMPU-Ht's between TT1 and TT2 to examine statistical significance demonstrated none ($p > 0.05$) was present. One possibility that may explain why there was no statistical difference is because the familiarity of the push-up exercise was not sufficient enough to create learning effect. Practically, we can see a difference in the increase in CMPU performance so practitioners would benefit from assessing the test more than twice in a week and may want to include more trials. The President's Council of Physical Fitness have norms starting at 6 years old for the PU which adds support to the statement by Shim et al. (2001), "...to avoid the confounding influence of motor learning, a field test should not require much practice, but consist of basic motor skills." (p. 193) The CMPU's familiarity among participants may aid in its use as a method to monitor and assess upper-body muscular extensor performance.

Practical Application

Strength and conditioning coaches need to be able to assess the status of their athletes by using reliable and valid devices to obtain sport specific performance values that may assist in developing strength and conditioning plans, while also monitoring progression. The JJ in the short-term may fill that gap as a tool to assess relative upper-body extensor muscle performance based on its relative reliability and relative validity results. Additionally, the JJ needs further investigation as it demonstrates few points of validity and lacks evidence of absolute validity in the current study. One caveat to the use of the JJ should be that there may be large variability in the results and should be

considered a guide and not as absolute agreement. Furthermore, strength and conditioning coaches would be advised to perform multiple test sessions with a minimum of three repetitions to evaluate the athlete's upper-body muscle extensor performance capabilities. The current study results of C MPU-Ht obtained with a JJ should be viewed with caution until further research is completed in establishing a more reliable and valid test to assess upper-body muscle extensor performance.

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