Using counter-movement push-up as a field test for upper-body extensor power

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Abstract

There is a paucity of research that examines the force-time variables of the counter-movement push-up (CMPU) and no research that examines the relationship between force-time variables and the vertical displacement (VH) associated with a CMPU. The purpose of the current study was two folds a) to investigate the relationships between CMPU-VH and the force-time variables (F-T) for the CMPU: peak force (PF), peak power (PP), peak rate of force development (PRFD), and impulse (IMP), and b) to examine evidences to support the validity for using CMPU as a measure of upper-body extensor power. Fifteen subjects (13 = males and 2 = females); (mean ± SD) age = 26.87 ± 2.72 years, height = 178.83 ± 7.92 cm, body mass = 84.85 ± 15.53 kg, and body fat percent = 17.31 ± 6.20 % volunteered for the study. The test-retest trials took place 48-72 hours apart to minimize the influence of fatigue and accommodate weekend, school, or work schedules. A 3-D motion capture method (10 Camera Raptor-E Digital Real Time Camera System) was used to measure CMPU-VH using reflective markers placed on specific anatomical landmarks on the surface of the skin in the Motion Analysis Lab and collected at a sampling rate of 120 Hz.

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CMPU kinetic data were sampled at 400 Hz using a BP400600 (2000lb capacity) force platform (FP). The resultant values were CMPU-VH = 24.64 ± 7.01 cm, PRFD = 6,254.93 ± 4409.89 $N \cdot s^{-1}$, IMP = 198.40 ± 77.99 N·s, PP = 329.15 ± 178.06 W and PF = 477.74 ± 179.73 N. A Pearson Product Moment Correlations matrix between CMPU-VH and force platform derived force-time variables was determined; the highest value was PP (r = 0.81) and the lowest was PRFD (r =0.43). The results provide some support for using the CMPU as a practical field test for assessing upper-body muscular extensor power and also suggest that the CMPU may be useful exercise for the development of upper-body extensor power.

Introduction:

The assessment of upper-body power may be accomplished by a variety of methods in both laboratory and field settings [1, 2, 3] with linear transducers or force plates yielding the highest reliability and validity values. Although methods using linear transducers or force plates provide the “best” acquisition of force-time variables [1, 2, 4, 5], their practicality limits use to laboratory settings that are not typically accessible to strength and conditioning (S&C) and sport coaches. However, upper-body power is an important attribute for many sport skills, leading S&C and sport coaches to seek out field tests [3] that are low cost and conducive to being used to assess large numbers of participants. There are numerous lower-body power field tests such as vertical jumps, horizontal jumps, change of direction, linear speed and strength lifts that only require tape measures, stop watches, or free weights. These types of tests have been utilized by coaches to establish baseline values and assess the effectiveness of training programs. However, the number of field tests for upper body power is far fewer than the number of field tests for lower-body power [1, 3]. Contributing to the lack of options for upper-body power field tests is the lack of research on upper-body movement patterns. Additional research examining force-time variables associated with movement patterns similar to those involved in upper-body sport skill performance is needed [4].

A common upper-body action in sports involves elbow extension and horizontal adduction or flexion of the shoulder joint as observed in the shot put. The medicine ball chest throw [1] is a field test that has been used to assess upper-body power based upon the assumption that the medicine ball chest throw uses some of the same muscular actions and joint movements used in upper-body sport skills. It would be helpful if research were available on more upper-body power movements.

The counter-movement push-up (CMPU) is a movement pattern requiring upper-body muscular extensor power that has received little attention from sport scientists. There have been a number of studies that have investigated the traditional push-up [6, 7, 8], but the traditional push-up measures strength rather than power since the push-up is not done rapidly. Force-time variables for the various plyometric push-ups (PPU), which do require upper-body power, have been published [2, 4]; but the execution of the CMPU is different from the PPU. The CMPU is begun with the elbows extended in a standard push-up position, followed by the lowering of the shoulder and trunk toward the ground, culminating with a rapid change of direction and extension of the elbows, driving the body upward. The PPUs studied by Koch et al. [2] and Moore et al. [5] consisted of a clap push-up and a drop push-up from a box, movements that are distinctly different from the CMPU. Hrysomallis and Kidgell [4] examined the impact of acute supine bench pressing on CMPU force-time variables, but this is the only study that has examined the force-time variables for a CMPU. Furthermore, Hrysomallis and Kidgell [4] did not examine the relationship between CMPU force-time variables and a variable that could be assessed to facilitate the use of the CMPU as a field test. The vertical height achieved during a CMPU is a variable that might be measured to facilitate the use of the CMPU as an upper-body power test in much the same way that vertical height is measured when using the counter-movement vertical jump as a lower-body power test.

Research Objectives:

The present study aims:

1. To investigate the relationships between CMPU-VH and the force-time variables (F-T) for the CMPU: peak force (PF), peak power (PP), peak rate of force development (PRFD), and impulse (IMP).
2. To examine evidences to support the validity for using CMPU as a measure of upper-body extensor power.

Research Hypotheses:

1. There will be statistical significant differences between CMPU-VH and the force-time variables (F-T) for the CMPU: peak force (PF), peak power (PP), peak rate of force development (PRFD), as well as impulse (IMP).
2. There will be evidences in support of using CMPU as a measure of upper body extensor power.

Key words: counter-movement push-up, peak force, peak power, peak rate of force development, impulse, vertical displacement.

Methods:

Experimental Approach to the Problem A cross-sectional, test-retest design was used to observe select F-T variables associated with the performance of the CMPU. The 15 subjects recruited for the study reported to a biomechanics laboratory on three separate occasions. A schematic of the study timeline is presented in Table 1. The first laboratory session served as an opportunity for collecting demographic information, starting hand positions, and familiarizing the subjects with the CMPU technique and the study protocol. The second and third sessions involved test and retest of the CMPU with simultaneous collection of F-T variables and CMPU-VH. A force platform was used to obtain the CMPU F-T variables (PP, PF, IMP, and PRFD) and a three-dimensional motion capture method (10 Camera Raptor-E Digital Real Time Camera System) was used to measure CMPU-VH using reflective markers placed on specific anatomical landmarks on the surface of the skin. Multiples sessions were used if the subject was unfamiliar with the CMPU technique.

Table (1)

Timeline and testing procedure for the current study

Initial Laboratory Session(s)	First session 1-2 Weeks	Second session	Time between sessions	Third session
Testing procedure	Familiarization to the test procedures	TT1 (Test)	48-72 hours	TT2 (Re-test)

Subjects:

All subjects in the present study completed a consent form and were informed of the requirements of the study, which was conducted with the approval of the university's Institutional Review Board. Fifteen healthy college students (13 = males and 2 = females) were recruited from the exercise and sport science program (mean ± SD) age = 26.87 ± 2.72 years, height (Ht) = 178.83 ± 7.92 cm, body mass (BM) = 84.85 ± 15.53 kg, and body fat percent (BF) = 17.31 ± 6.20 %. Only trained subjects were recruited, 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 subjects were engaged in a strength training program while 4 subjects engaged in aerobic exercises, recreation basketball, or muscular endurance training. Subjects 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:

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 (kg). Participant's Ht was measured barefoot with a wall mounted ruler and right angle block in centimeters (cm) and recorded to the nearest millimeter. A seven site skin-fold (7-SKF) method was used to predict body fat percent. All skin-fold measurements were completed by the lead investigator who is a certified strength and conditioning specialist (CSCS) with over 20 years of experience using the Lange Caliper (Beta Technology, Santa Cruz, CA). Following an upper-body dynamic warm-up (DWU), described in Table 2, which was performed prior to practicing the CMPU, subjects received instruction on the CMPU technique. Subjects were instructed to select a comfortable hand position for the CMPU. Hand positions were recorded as cm deviating from the center point of a template positioned on the floor parallel to the hands, a technique used to improve consistency between testing sessions. The CMPU was initiated with the hands on the force plate, elbows fully extended, shoulders flexed to approximately 90°, torso and legs in a straight line, and feet together with toes and balls of feet in contact with the ground. Subjects rapidly lowered their upper-body to a self-selected depth, but prior to contact with the force platform, then rapidly changed directions upwards pushing their body into the air until the elbows were fully extended and hands broke contact with the force platform [4, 9]. All subjects were allowed as many attempts to practice the CMPU as they felt necessary, but a minimum of 5 had to be performed during the initial laboratory session. A practice trial was considered successful if the subject's hands lost contact with the floor during the CMPU and the subject expressed comfort with the protocol. Some of the subjects had utilized the CMPU in their physical training and were able to demonstrate successful CMPUs during the initial laboratory session. Other subjects performed CMPU's on at least 2 different days prior to the TT1 collection of data.

Table (2)
Upper-body dynamic warm-up (DWU)

DWU Activity	Volume
Jumping jacks	1 minute
Push-ups	x10 repetitions
Body weight squats	x10 repetitions
Dynamic hip flexor stretch "Scorpions"	x10 repetitions each leg
Horizontal arm swings – Forward &Backward	x10 repetitions each direction
Sagittal arm swings – Forward & Backward	x10 repetitions each direction
Standing torso rotation	x20 repetitions

Testing Trials:

Testing trials (TT) took place 48-72 hours apart to minimize the influence of fatigue and accommodate weekend, school, or work schedules. For TT1, participant BM was measured and reflective markers for the 3D motion analysis were positioned. The following bony landmarks were used: 3rd metacarpal, radial and ulnar stylus, 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-VH 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. The DWU was completed after reflective markers were positioned. Subjects performed the CMPU with their hands positioned on a BP400600 (2000lb capacity) force platform (FP) (Advanced Mechanical Technology, Inc., Watertown, MA), which was used to measure the F-T variables at a sample rate of 400 Hz.

The subjects CMPU-VH was determined simultaneously by measuring, to the nearest 0.01 cm, the displacement of C7-T1 reflective marker through motion analysis. Both the TT1 CMPU and TT2 CMPU with the highest PF, reported as Newtons (N), which was used to obtain the PRFD, PP, IMP, and CMPU-VH 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 $N·s^{-1}$. PP was determined by taking the product of PF and CMPU-VH, and dividing the product by the time from PF to the point of take-off (P = (f x d)/ t) and was reported as watts (W). 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} x time) and was reported in N·s.

Statistical Analysis:

Descriptive statistics were calculated for the CMPU-VH, PF, PP, and PRFD values associated with highest CMPU-PF during both TT1 and TT2. An intraclass correlation coefficients (ICCs), coefficients of variation (CV%), standard error of the means (SEM), and paired t-tests were used to examine the TT1 to TT2 (day-to-day) reliability of the CMPU F-T variables. Pearson Product Moment correlation coefficients were used to examine relationships between CMPU-VH and PF, PP, IMP, and PRFD, with an a priori of $r > 0.70$ set to indicate a high relationship [3, 10]. All statistical analyses were performed on PASW Statistics 18.0 (Formerly SPSS; IBM Inc., Chicago, IL).

Result:

Descriptive statistics for the CMPU F-T variables and motion analysis CMPU-VH associated with the highest PF value for TT1 and TT2 are presented in Table 3. The ICCs and associated within-subjects CV% and SEM values for the test-retest variables are also presented in Table 3. The paired t-test between the test-retest CMPU PF was significant at the $p = 0.05$ level. Because the statistical difference between the TT1 and TT2 PF values and the relatively high CV% values associated with the TT1 to TT2 reliability data, there may have been a learning effect for performance of the CMPU. Therefore, only the values associated with the TT2 CMPU F-T variables and CMPU-VH (see Table 3) were used to derive the Pearson Product-Moment coefficients for CMPU-VH and the force platform derived CMPU F-T variables. The ICCs between CMPU-VH and F-T variables meeting the a priori *r* of 0.70 can be seen in Table 4, and all correlations were statistically significant ($p \leq 0.05$).

Table (3)
Test-retest reliability of force-time variables from motion analysis and force platform (Mean ± SD)

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

Pearson Product Moment correlation coefficients were used to examine relationships between CMPU-VH assessed with motion analysis and the force platform variables of PRFD, PF, IMP, and PP are presented in Table 4. The result revealed a moderate positive correlation (r = .43) between CMPU-VH and PRFD. In addition, a relatively high positive correlation was observed between CMPU-VH and PF (r = .70), and PP (r = .081), respectively. Lastly, high moderate positive correlation (r = .56) was also observed between CMPU-VH and IMP.

Table (4)

Pearson Product Moment Correlations between CMPU-VH and force platform derived F-T variables.

Force-time Variable	CMPU-VH
PRFD (Peak Rate of Force Development)	0.43*
PF (Peak Force)	0.70*
PP (Peak Power)	0.81*
IMP (Impulse)	0.56*

.Note. *Statistically Significant ($p \leq 0.05$)

Discussion:

At the time of the current study, Hrysomallis and Kidgell [4] and Koch et al. [2] are the only investigators to have published work on the force-time variables for a CMPU. The current study extends the work of Hrysomallis and Kidgell [4] and Koch et al. [2] with measures of CMPU-VH and the additional calculation of PP which allows for inferences as to the potential use of a CMPU as a field test for upper-body power (See Table 5). The relatively high correlations between CMPU-VH assessed with motion analysis and force platform PF (r = 0.70) and PP (r = 0.81) provide some support for using the VH achieved during a CMPU as a practical field test for assessing upper-body muscular extensor PF and PP production. However, the use of CMPU-VH as a field test depends on the identification of techniques to measure VMPU-VH that are less costly than motion analysis. The portable contact switch mats that are used to calculate vertical jump height for counter-movement vertical jumps may be one example of an expensive tool for assessing CMPU-VH; however, the validity and reliability of the use of contact switch mats with a CMPU remains unexplored.

Table (5)
Study comparison of CMPU-VH and force-time variables means for TT2 (re-test), and Hyrsomallis and Kidgell [4] (Mean ± SD).

Study	CMPU-VH (cm)	PRFD (N·s^{-1})	IMP (N·s)	PP (W)	PF (N)
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Hyrsomallis 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	314.55 ± 182.07	477.74 ± 179.73

Note. n/a = not reported in study

In addition to extending the work of Hrysomallis and Kidgell [4] and Koch et al. [2], the results of the current study revealed that the PP values observed compare favorably with values reported for other upper-body muscular extensor tests reported in the literature. [1,3]. The current study observed a PP of 314.55 ± 182.07 W, which is at the lower end of the range of the PP values (303 W) observed by Shim et al. [3] who used timing devices to calculate PP during a bench press movement. The current study PP values were considerably greater than the PP values by Cronin and Owen [1] for 10 kg chest passes (161.0 W) whose subjects were females, while only two of the subjects in the current study were females. In addition, the differences in PPs between the current study and the work of both Shim et al. and Cronin and Owen probably also reflects the relative loads moved. For the current study, the subject's completion of a CMPU requires a displacement of a percentage of BM, while Shim at al. [3] required a displacement of 75% 1RM bench press. Cronin and Owen [1], on the other hand, used a fixed load of 10 kg. Furthermore, while performing a CPU requires the displacement of approximately 60% of the participant's BM, the actual load varies depending on the amount of upper-body musculature, upper-body fat mass, trunk and limb lengths, and hand position [4, 7]. Since relative load is a major determinant of muscular power production, the differences in the upper-body PP values reported in the literature probably reflect differences in the relative loads used and suggest that S&C coaches should consider the requisites of specific sport skills as they select an upper-body power test. For example, upper body power tests that rely upon using a fixed load, as was the case in the Cronin and Owen study, might be most appropriate for sport skills that require creating power with a fixed load as is true for the shot putter. Conversely, for assessing sport skills that require creating upper-body power with large loads, the CMPU-VH might be more an appropriate test.

The differences in absolute upper-body PP values between CMPUs, 75% 1RM bench presses, and 10 kg fixed load bench presses, suggests that there may be a need for measuring relative PP values for upper-body power tests. Since CMPU-VH is used in the calculation of PP, the influence of trunk length and limb length might also be considered in calculating a relative PP. If BM is to be used in the calculation of relative PP, future research should consider whether or not BM should be measured from a standing position or with the scale under the hands while in the CMPU starting position.

While there was a strong relationship between PF and CMPU-VH which supports the use of CMPU-VH as a test of upper-body power, this was not the only finding in support of CMPU-VH as a test of upper-body power. In the current study there were 4 of the 15 subjects whose preferred mode of training was aerobic exercise rather than resistive exercise. These aerobically trained subjects had lower CMPU-VH values than did the strength trained subjects. Greater CMPU-VH may be related to the strength trained subjects having the potential for activation of a greater number of Type II muscle fibers, improved neural-muscular performance, and better intermuscular coordination compared to the aerobically trained subjects [11]. The limited number of aerobic trained subjects prevented a robust analysis of the data and future studies to examine the value of CMPUs as an assessment tool may benefit from a comparison of CMPU variables for strength trained athletes and aerobically trained athletes.

The rational for using CMPU-VH as a field test for upper-body power is based on the widespread use of vertical jump height as a test of lower-body power. It should be noted however, that Knudson [12] suggests that the vertical displacement of a countermovement jump may not be appropriate for determining force-time variables associated with the jump and so the term power is inappropriate. Therefore, the same criticism may apply to the CMPU-VH and the assessment of upper-body extensor muscle force-time variables using the CMPU. In spite of this potential limitation related to the use of the term power, the high correlation of PF to the CMPU-VH suggests that the CMPU may be a method to assess the performance of the upper-body extensor musculature.

Research examining the counter-movement jump suggests that jump height is enhanced due to the increased time available for force development due to the counter-movement rather than enhanced utilization of stored elastic energy [13, 14]. The influence of the muscular system's storage and release of the elastic energy as a result of the eccentric action, as during a CMPU, may only contribute to increased force production if the time period is brief [15]. Eccentric time periods less than 250 ms may see the utilization of elastic energy, but if an athlete does not immediately switch from an eccentric to concentric action, the eccentric time period increase may result in the stored elastic energy to be dissipated as heat [16]. The current study was not designed to assess the duration of the eccentric time period during the CMPUs, but the research on counter-movement jumps suggests that CMPU-VH may be a method to assess the neuromuscular system's ability to increase PF by increasing the upper-body's time to develop force during the CMPU.

Athletes that perform the CMPU as part of a strength and conditioning plan or as an assessment may be able to change more quickly from the countermovement phase to the concentric phase, resulting in more utilization of stored elastic energy and a higher CMPU-VH. Additionally, previous work by Wilson et al. [11] suggests that increased muscular tendon stiffness may have a greater relationship with concentric performance in comparison to eccentric performance. This information suggests that trained subjects with greater upper-body muscular tendon stiffness may display higher force-time variable levels in comparison to untrained subjects. Future studies may benefit from categorizing subjects into trained and untrained groups with specific muscle qualities for analysis of CMPU performance. These categories may include reactive strength, eccentric strength, or concentric strength for determining if alternative testing protocols are necessary for trained subjects.

Although the high correlation between PF and CMPU-VH observed in the current study did yield some evidence in support of using CMPU-VH as a method for assessing upper-body power, the authors acknowledge that a limitation to the current study is the large CV% in some of the force-time variables. This variability could be a reflection of variability in CMPU technique between TT1 and TT2 or a learning effect. Since the TT2 values are generally higher than the TT1 values, we believe that the large CV%s may be a result of a motor learning. Furthermore, some subjects did not curtail their training up to and during the TT1 to TT2 time periods. Therefore, training adaptations may have contributed to the increased TT2 CMPU performances. The increases in PRFD and IMP from TT1 and TT2 support the concept that the subjects experienced improvements in their intermuscular and intramuscular coordination [17] between the 2 sessions. Subjects in future studies may benefit from a 1–2 week training program to minimize any acute neuromuscular effects on the force-time variables.

Other researchers [12, 18], when examining RFD and jump VH have reported high CV% and both high and low correlations between RFD and jump VH [12,18]. It is conceivable that these differences reflect methodological differences in determining PRFD. The current study determined PRFD by establishing the steepest gradient of 10 consecutive data points in the first 50 ms, and future studies would improve greater insight by examining RFD at time periods of 25, 50, 100, 150, and 250 ms. to determine how different sampling times influence F-T to CMPU-VH relationships and CV% between testing sessions.

Lastly, the relatively high correlation between PF and CMPU-VH in the current study may be related to the fact that the video motion capture analysis and force platform data collection occurred simultaneously during the execution of a CMPU. Whenever possible, simultaneous data collection should be used.

In conclusion:

Based on the relatively high correlation between CMPU-VH and PF observed in the current study, there is some evidence in support for using CMPU-VH as a measure of upper-body extensor power. Considerably more research is needed to obtain evidence in support of the validity of CMPU-VH for use with various athlete populations and to better understand the amount of practice time needed to prevent a learning effect from compromising CMPU-VH assessment. Lastly, more research is needed to identify low cost procedures for accurately and reliably assessing CMPU-VH.

Practical Application:

Female and male subjects demonstrated the ability to execute a CMPU and CMPU-VH was related to PF generated during the CMPU, suggesting that CMPUs could be used as an exercise in the training programs for various sports that require upper-body extensor muscle performance. Both female and males athletes might benefit from such training. If there is wide spread adoption of CMPUs as a training exercise, consistency in performing the CMPU would benefit the use of CMPU-VH as a measure of upper-body extensor power. However, more research is needed to establish inexpensive techniques for measuring CVMPU-VH before the CMPU can be assessed in field settings.

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