The Test-Retest Reliability of Force Plate-Derived Parameters of the Countermovement Push-Up as a Power Assessment Tool

Gemma N. Parry, Lee C. Herrington, and Ian G. Horsley

Context: Muscular power output of the upper limb is a key aspect of athletic and sporting performance. Maximal power describes the ability to immediately produce power with maximal velocity at the point of release, impact, or takeoff, with research highlighting that the greater an athlete's ability to produce maximal power, the greater the improvement in athletic performance. Despite the importance of upper-limb power for athletic performance, there is presently no gold-standard test for upper-limb force development performance. **Objective:** The aim of this study was to investigate the test-retest reliability of force plate-derived measures of the countermovement push-up in active males. **Design:** Test-retest design. **Setting:** Controlled laboratory. **Participants:** Physically active college athletes (age 24 [3] y, height 1.79 [0.08] m, body mass 81.7 [9.9] kg). **Intervention:** Subjects performed 3 repetitions of maximal effort countermovement push-up trials on Kistler force plates on 2 separate test occasions 7 days apart. **Main Outcome Measures:** Peak force, mean force, flight time, rate of force development, and impulse were analyzed from the force-time curve. **Results:** No significant differences between the 2 trial occasions were observed for any of the derived performance measures. Intraclass correlation coefficient and within-subject coefficient of variation calculations indicated performance measures to have moderate to very high reliability (intraclass correlation coefficient = .88-.98), coefficient of variation = 5.5%-14.1%). Smallest detectable difference for peak force (7.5%), mean force (8.6%), and rate of force development (11.2%) were small to moderate. **Conclusion:** Force platform-derived kinetic parameters of countermovement push-up are reliable measurements of power in college-level athletes.

Keywords: upper-limb power, meaningful difference, force-time curve

Upper-limb muscular power output is a fundamental and highly desirable characteristic across a number of explosive short-duration sports.^{1,2} Because upper-limb muscle power output is considered to be a principle movement skill and a key aspect of sporting performance and athletic ability, it is important to identify ways of assessing an athlete's ability to produce upper-limb force in order to not only understand an individual's performance potential but also monitor training program effects, long-term development, and talent identification.

Despite the importance of upper-limb muscular power, there is presently no gold-standard test of upper-limb force development performance. Previously, medicine ball throws, bench press, and timed push-ups have been utilized to monitor and assess training regime effectiveness with regard to upper-limb muscular performance.³⁻⁷ There is a paucity of research analyzing upper-limb power production via a plyometric push-up, with only a few studies investigating force plate-derived kinetic data to assess upper-limb power output.⁵⁻⁷ There is evidence of moderate to high reliability with strong test-retest correlations (intraclass correlation coefficient [ICC] = .84-.96) for the kinetic parameters of force, impulse, and rate of force development (RFD) between testing sessions for bench press and explosive push-up in active male individuals⁶; however, due to a focus on heavy resistance exercise effects, the

stretch-shortening cycle movement, and no reported outcome on vertical displacement, it is unknown whether these parameters can be reliably measured during countermovement push-up (CMPU) performance. Researchers⁷ have also reported a trend of high reliability (ICC = .85-.97) for peak force (PF) during 4 plyometric push-up variations. Furthermore, a recent study solely investigating the reliability of a plyometric push-up⁵ reported excellent between-test reliability (ICC = .8-.96) for PF for subelite rugby league players. However, RFD did not demonstrate the same reliability (ICC ≤ .84). Despite the availability of commensurable literature, Hogarth et al⁵ and Koch et al⁷ attributed result disparities to lack of subject familiarization with the technique.

Timed push-ups have been highlighted as poor for assessment of force-time performance due to an athlete only being required to move 60% of their body mass—as opposed to the 100% required for power⁸—and are arguably more likely to be a measure of muscular endurance. Cronin et al⁹ demonstrated that a countermovement bench press throw increased peak throw power by 11.7% across a range of 30% to 80% of an individual's repetition maximum, indicating that the stretch-shortening cycle in the upper limb may have been enhanced in relation to power output. Although the feet act as a pivot point by remaining in contact with the floor, the explosive similarities and similar displacement of body mass through a vertical plane in both the countermovement jump (CMJ) and CMPU make it reasonable to assume that the force-time characteristics witnessed and reported in the CMJ literature may also apply to the CMPU as an evaluator of performance.

Generation of upper-limb power is an important factor across a range of sports.^{1,2} Valid and reliable protocols for its assessment and development are valuable measurements that can be utilized to impact sporting performance. While a performance test might demonstrate high reliability, this does not always directly represent

Parry is with GB Boxing, English Institute of Sport, Sheffield, United Kingdom; and the Human Performance Laboratory, Directorate of Sport, Exercise and Physiotherapy, School of Health Sport and Rehabilitation Sciences, University of Salford, Salford, United Kingdom. Herrington is with the School of Health, Sport and Rehabilitation Sciences, University of Salford, Manchester, United Kingdom. Herrington and Horsley are with Physiotherapy Department, English Institute of Sport, Manchester, United Kingdom. Parry (g.parry1@edu.salford.ac.uk) is corresponding author.

a substantial change in performance due to random error and learning effect measurement error.¹⁰ Smallest detectable differences (SDDs) allow practitioners to deduce meaningful changes in performance rather than changes due to measurement errors.¹¹ Therefore, there is a need to further understand and rationalize the use of CMPU as a tool to measure upper-limb power, which could potentially give coaches and practitioners a reliable measurement tool that provides recognized meaningful differences in upper-limb power output within sporting and active populations.

Further research is required to understand relationships between force–time characteristics because at present there is a lack of published information that reports the reliability of CMPU as a testing protocol for upper-limb performance. The aim of this study, therefore, was to investigate the test–retest reliability of force plate–derived measures of CMPU in active males. A secondary aim was to explore the SDD that occurred between trials for meaningful changes.

Methods

Experimental Approach to the Problem

A single-group, repeated-measure design was used, with 3 repetitions of maximal-effort CMPU on 2 separate testing sessions 7 days apart.

Participants

A total of 10 male college athletes (age 24 [3] y; height 1.79 [0.08] m; body mass 81.7 [9.9] kg) with a minimum of 1 year of Olympic lifting training history participated in this study. The institutional review board approved the investigation and preceding testing, and all subjects provided written informed consent.

Procedures

Three repetitions of maximal-effort CMPU trials, with 2 minutes of rest between trials, were completed on 2 separate occasions at the same time of day, 7 days apart, in order to determine reliability when following a standardized protocol. Trials were performed on 2 portable force plates (Kistler type 9286; Kistler, Winterthur, Switzerland), and Bioware Software (version 5.11; Bioware Software, Switzerland) was used to collect kinetic data at a sampling frequency of 1000 Hz. During testing, the participant's weight was evenly distributed with a force plate beneath each hand, the shoulders at 90 degrees of flexion, with the torso, legs and elbows extended and malleoli and feet together. Following a 3-second countdown, the participant immediately lowered his torso rapidly toward the force plate, then immediately pressed vertically as high as possible, aiming for maximal height and trunk elevation, with elbows extended and hands clearing the plate, and landing back on the force plate with both hands at the same time (Figure 1). Performance variables (PF [in newtons]; mean force, MF [in newtons]; peak RFD [in newtons per second], flight time [in seconds], and impulse [in newton per second]) were taken from the force–time curve (Figure 2), and data were filtered using a Butterworth low-pass filter at 8 Hz. The greatest PF determined the best CMPU effort for each participant.

Statistical Analysis

Statistical analysis was carried out using SPSS version 25 (Chicago, IL) for Windows. Paired sample *t* tests were performed

Figure 1 — Example of counter-movement push-up.

Figure 2 — Force trace from a subject performing counter-movement push-up.

to deduce any significant changes in performance measures between trial sessions. ICC and within-subject coefficient of variation (CV%) were calculated with 95% confidence intervals to determine relationships between test–retest reliability and reproducibility. SEM and SDD were also included to represent and identify the smallest clinically worthwhile change that was statistically significant using $SD [\text{pooled}] \times \sqrt{1 - ICC}$ for SEM and $1.96 \times \sqrt{2 \times SEM}$ for SDD.¹² Data are presented as mean (SD), and significance is set at $P \leq .05$.

Results

Descriptive and reliability statistics are presented for each derived parameter in Table 1. Paired sample *t* tests indicated no significant differences between the 2 trials ($P > .05$) for any of the derived performance measures. ICC and within-subject coefficient of variation calculations indicated that the performance measures had moderate to very high reliability (ICC = .88–.98, CV% = 5.5–14.1). Within-subject calculations appeared to demonstrate moderate to high reliability (CV = 1.7%–6.9%, ICC = .96–.98) for the derived parameters of PF, flight time, MF, and impulse; only RFD was outside acceptable standards of reliability (CV = 14.1%, ICC = .87). SDD for PF (7.5%), MF (8.6%), and RFD (11.2%) was small to moderate.

Table 1 Values of Reliability Statistics for Countermovement Push-Up-Derived Parameters (n = 10)

Derived parameter	Trial 1	Trial 2	SEM	CV%	ICC	SDD	SDD%
Flight time, s	0.3 (0.0)	0.3 (0.0)	0.0	6.9	.964	0.0	0.0
Peak force, N	1171 (41)	1140 (48)	31.1	3.9	.963	86.3	7.5
Mean force, N	589 (14)	587 (6.4)	1.7	1.7	.967	50.3	8.6
Rate force development, N/s	2585 (137)	2599 (147)	105.1	14.1	.878	291.3	11.2
Impulse, N·s	77.5 (10.9)	73 (7.5)	7.1	5.5	.983	19.7	26.1

Abbreviations: CV, coefficient of variation; ICC, intraclass correlation coefficient; SDD, smallest detectable difference. Note: Values are presented as mean (SD).

Discussion

The focus of this article was the test–retest reliability of the force time–derived parameters of a CMPU in college-level athletes. Presently, there are no clear, acceptable standards of reliability for a CMPU. However, $CV\% < 10\%$ and ICC values of $> 75\%$ have been shown to be demonstrative of good reliability for measures obtained during CMJs.² The findings of this study indicate that CMPU force plate–derived parameters are reliable indicators of performance in college-level athletes. Previous research^{5–7} has reported comparable values of moderate to high test–retest reliability for force time–derived parameters from variations of push-ups within Rugby League ($CV = 2.3\%–11\%$) and mixed cohorts of recreationally active participants and active duty marines ($ICC = .85\%–.97\%$), with MF ($CV = 4.8\%$) demonstrating the best reliability. Similar to the mixed-cohort participants,^{6,7} the participants in this investigation were college athletes with a minimum 1-year history of Olympic lifting and some plyometric training, and although they may not have participated in push-up exercises as regularly as elite athletes, a high reliability ($ICC = .87\%–.98\%$) of the derived parameters between test sessions was still demonstrated. This is an important finding because it suggests that CMPU force plate–derived kinetic data are reliable performance measure in elite, trained, and recreationally trained college populations.

Given the widely reported body of evidence for the high reliability of peak measures of force and power within the CMJ literature, it is not surprising that a parallel high reliability for the parameters of MF ($CV = 1.7\%$) and PF ($CV = 3.9\%$) was found for CMPU. The higher reliability of the average value is potentially due to the ultimate PF values being unaffected by negligible variations in PF.¹⁰ Despite the reported reliability of CMPU parameters, RFD demonstrated poor reliability within this study ($CV = 14.9\%$). In addition, although the results for ICC ($ICC = .87\%$) were comparable with another study,⁶ it is questionable whether it is a reliable parameter. Likewise, RFD demonstrated poor reliability within the previously mentioned studies.^{5–7} Although there is a paucity of additional commensurable literature for CMPU, our findings are consistent with poor RFD reliability values ($CV = 11.8\%$, $ICC = .75\%$) presented within the CMJ literature²; given the importance of RFD to fast, forceful muscle contraction,¹⁰ the results should be interpreted with caution until RFD reliability is clearly established. Methods for measuring CMJ performance affect RFD reliability; impulse methods have been shown to have lower associated errors to deduce RFD comparative with flight-time methods,^{2,10} which may account for the poor reported reliability of RFD. When assessing force, practitioners should be looking for changes from 8% to 9% in order to determine meaningful change, particularly if they are using CMPU to monitor

training program effects and long-term athlete development because tests that are deemed reliable are not necessarily the most effective for monitoring performance changes.

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