Variability and influence of eccentric kinematics on unilateral vertical, horizontal, and lateral countermovement jump performance

Cesar Meylan  
*Edith Cowan University*

Kazunori Nosaka  
*Edith Cowan University*

Jonathan P. Green

John B. Cronin  
*Edith Cowan University*

Follow this and additional works at: [https://ro.ecu.edu.au/ecuworks](https://ro.ecu.edu.au/ecuworks)

Part of the [Sports Sciences Commons](https://ro.ecu.edu.au/ecuworks)

10.1519/JSC.0b013e3181ae7961  
Variability and Influence of Eccentric Kinematics on Unilateral Vertical, Horizontal, and Lateral Countermovement Jump Performance

Cesar M.P. Meylan,1,3 Ken Nosaka,1 Jonathan P. Green,2 and John B. Cronin1,3

1School of Exercise, Biomedical and Health Sciences, Edith Cowan University, Joondalup, Australia; 2ICON Technologies Pty Ltd., Victoria Park, Australia; and 3Institute of Sport and Recreation Research New Zealand, Auckland University of Technology, Auckland, New Zealand

Abstract

Meylan, CMP, Nosaka, K, Green, JP, and Cronin, JB. Variability and influence of eccentric kinematics on unilateral vertical, horizontal, and lateral countermovement jump performance. J Strength Cond Res 24(3): 840–845, 2010—The purposes of this study were to determine the (a) magnitude of variability associated with certain eccentric variables (eccentric peak velocity, displacement, and ground contact time) during unilateral countermovement jump performance (vertical [VCMJ], horizontal [HCMJ], and lateral [LCMJ]); (b) differences between limbs as well as between jumps; and (c) relationship between jump performance and the eccentric variables of interest. The jumping ability in 3 directions (VCMJ, HCMJ, and LCMJ) of 30 field sport athletes were assessed. The variability (coefficient of variation [CV]) of the eccentric variables was the lowest for the VCMJ (CV = 8.5–10.6%) and the highest for the HCMJ (CV = 11.7%–13.5%). No difference was found between limbs in the variables of interest. Significant statistical differences (p, 0.05) across the different jumps were found in the eccentric variables (9.1–29.4%). No significant correlations between the eccentric variables and jump performance were found for the VCMJ; however, significant correlations were found between jump length and eccentric displacement or eccentric peak velocity in both HCMJ (r = −0.60 and 0.57) and LCMJ (r = −0.54 and 0.37), respectively. It appears that in the absence of instruction and standardization of the countermovement, eccentric phase kinematics remains relatively stable over trials. In terms of the between jump analysis, it appears that the eccentric phase kinematics are relatively unique to each jump and directionally specific and therefore may need to be trained accordingly.

Key Words: force, velocity, reliability

Introduction

If active muscle is stretched immediately before shortening, it generally exhibits higher contractile force than without the prestretch (2). Such a combination of lengthening (eccentric phase) and shortening (concentric phase) contractions has been termed a stretch-shorten cycle (SSC) and has shown to enhance performance as measured by takeoff velocity or jump height (2). For example, the jump height of vertical countermovement jump, which is a typical SSC jump, is approximately 12–18% greater than that of squat jump, which is a pure concentric jump (1,4,10,18). Such effect is often referred to as an SSC enhancement (19).

The time between the eccentric and concentric phases of the SSC (coupling time), the time from the beginning of the eccentric contraction to the beginning of the concentric contraction (i.e., eccentric ground contact time [GCT]), the final muscle length (i.e., eccentric displacement), and stretch velocity (i.e., eccentric velocity) are factors of the eccentric phase that have been reported to affect the magnitude of SSC enhancement (3,5–7,20). It may be that small changes in these variables between trials have substantial influence on the jump performance and therefore need to be standardized. However, the variability associated with these critical determinants of jump performance are unknown for a typical countermovement jump (CMJ), nor is it clear whether this variability is the same across CMJs in vertical (VCMJ), lateral (LCMJ), and horizontal (HCMJ) directions. Such information is important in determining the level of familiarization and standardization needed for various assessment tasks.

Unilateral jump performance is often used to assess leg asymmetries in the clinical environment (13,22,23), but whether the participants use the same eccentric strategies with both legs remains unknown. Assessing eccentric
kinematic differences in a healthy population will provide insight into the expected asymmetry between limbs and can provide comparisons for clinical populations.

As suggested by other researchers (12,16,21), the eccentric phase is crucial in the force distribution and angle at takeoff in bilateral VCMJ and HCMJ. However, it is unknown whether the eccentric kinematics between jumps is similar and therefore whether training in 1 direction will transfer across all directions or planes of movement. In addition, it is unclear whether a particular eccentric pattern of movement (i.e., depth, time, and velocity of the eccentric phase) results in better jump performance. Therefore, the purposes of this article were, first, to determine the magnitude of variability associated with the kinematic eccentric variables (i.e., velocity, depth, and contact time) thought critical to jump performance in a unilateral fashion; second, to assess the difference between limbs in a healthy population; and third, to identify the characteristics of the eccentric phase between jumps and the relationship between these variables and jump performance.

**METHODS**

**Experimental Approach to the Problem**

Thirty team sport athletes performed 3 trials of a unilateral VCMJ, HCMJ, and a LCMJ to determine the intertrial variability of the eccentric displacement, peak velocity, and GCT and jump performance. Further analysis was conducted to determine whether a difference in the eccentric variables existed between the limbs and the jump type and the relationship of these variables to jump performance.

** Subjects**

Thirty team sport athletes (soccer, basketball, field hockey, and rugby) volunteered for this study, and their characteristics were age 21.9 ± 3.8 years, height 1.77 ± 0.06 m, body mass 75.5 ± 9.0 kg. All of them were club players who trained at least twice a week in their respective sports. None of the participants had a lower-body injury in the previous 6 months. All testing procedures and risks were fully explained, and participants were asked to provide their written consent before the start of the study. The study was approved by the Human Subject Ethics Committee of Edith Cowan University.

**Testing Procedures**

The testing session was scheduled more than 48 hours after a competition or physical training session to minimize the influence of fatigue. Before testing, the subject’s age, height, and mass were recorded, and leg dominance was defined as the preferred leg to jump with. Subjects performed a separate familiarization session a week before the testing session consisting of 3 to 6 trials until they could produce a continuous coordinated jump and controlled landing. Before the familiarization and testing sessions, each subject underwent a 10-minute progressive standardized warm-up consisting of 5 minutes of jogging followed by a series of dynamic movements (e.g., lunges, skipping). No passive stretching was performed before the testing session.

**Table 1.** Mean (±SD), coefficient of variation (CV%), and 95% confidence limits (CI) for eccentric variables of interest and jump performance for vertical (VCMJ) and horizontal (HCMJ) and lateral (LCMJ) countermovement jumps.

<table>
<thead>
<tr>
<th>Jumps</th>
<th>Mean ± SD</th>
<th>CV (%)</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>VCMJ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contact time (s)</td>
<td>0.37 ± 0.02</td>
<td>0.20 ± 0.05</td>
<td>0.87 ± 0.02</td>
</tr>
<tr>
<td>Displacement (m)</td>
<td>0.16 ± 0.03</td>
<td>0.20 ± 0.05</td>
<td>0.87 ± 0.02</td>
</tr>
<tr>
<td>Peak velocity (m/s²)</td>
<td>0.87 ± 0.03</td>
<td>0.20 ± 0.05</td>
<td>0.87 ± 0.02</td>
</tr>
<tr>
<td>Jump performance (m)</td>
<td>0.15 ± 0.02</td>
<td>0.20 ± 0.05</td>
<td>0.87 ± 0.02</td>
</tr>
</tbody>
</table>

**HCMJ**

<table>
<thead>
<tr>
<th>Mean ± SD</th>
<th>CV (%)</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contact time (s)</td>
<td>0.37 ± 0.02</td>
<td>0.20 ± 0.05</td>
</tr>
<tr>
<td>Displacement (m)</td>
<td>0.16 ± 0.03</td>
<td>0.20 ± 0.05</td>
</tr>
<tr>
<td>Peak velocity (m/s²)</td>
<td>0.87 ± 0.03</td>
<td>0.20 ± 0.05</td>
</tr>
<tr>
<td>Jump performance (m)</td>
<td>0.15 ± 0.02</td>
<td>0.20 ± 0.05</td>
</tr>
</tbody>
</table>

**LCMJ**

<table>
<thead>
<tr>
<th>Mean ± SD</th>
<th>CV (%)</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contact time (s)</td>
<td>0.37 ± 0.02</td>
<td>0.20 ± 0.05</td>
</tr>
<tr>
<td>Displacement (m)</td>
<td>0.16 ± 0.03</td>
<td>0.20 ± 0.05</td>
</tr>
<tr>
<td>Peak velocity (m/s²)</td>
<td>0.87 ± 0.03</td>
<td>0.20 ± 0.05</td>
</tr>
<tr>
<td>Jump performance (m)</td>
<td>0.15 ± 0.02</td>
<td>0.20 ± 0.05</td>
</tr>
</tbody>
</table>

*Significant (p < 0.05) difference between VCMJ and HCMJ or LCMJ.
†Significant (p < 0.05) difference between HCMJ and LCMJ.
Eccentric Kinematics of Unilateral Jumps

allowed because previous studies have demonstrated the negative impact on various jump variables (8,17,25).

In the testing session, participants performed 3 trials of the unilateral VCMJ, HCMJ, and LCMJ with each leg in a randomized order, with approximately 30 seconds of recovery between trials within jump type and 120 seconds between jump types. During every jump, participants were asked to keep their arms akimbo to eliminate arm swing. Participants self-selected the amplitude of the counter-movement to avoid changes in the coordination pattern. The VCMJ movement started on the designated testing leg and consisted in sinking and then jumping as high as possible in the ensuing concentric phase and landing on 2 feet. For the HCMJ, the same starting protocol was applied, but the subject then had to jump as far as possible and land on 2 feet. The starting procedure of the LCMJ was the same as the VCMJ and HCMJ, but the subjects had to jump laterally to the inside as far as possible and land on 2 feet. Vertical ground reaction force data were collected with an in-ground force plate (Kistler, model 9287B, Winterthur, Switzerland) using a sampling rate of 1,000 Hz, and the distance jumped during the HCMJ and LCMJ was measured to the nearest 0.01 m with a tape measure (Figure 1).

![Figure 1. Demonstration of unilateral lateral countermovement jump. A) Starting position on leg tested. B) Bottom position (end of eccentric phase). From bottom position, subject tried to jump as far as possible to side (here, left side) and land on 2 feet.]

<table>
<thead>
<tr>
<th>Table 2. Intercorrelations between eccentric variables of interest and vertical (VCMJ), horizontal (HCMJ), and lateral (LCMJ) countermovement jump performance.</th>
</tr>
</thead>
<tbody>
<tr>
<td>VCMJ performance</td>
</tr>
<tr>
<td>Contact time (s)</td>
</tr>
<tr>
<td>Displacement (m)</td>
</tr>
<tr>
<td>Peak velocity</td>
</tr>
</tbody>
</table>

*Correlation is significant at $p \leq 0.05$.
†Correlation is significant at $p \leq 0.01$. |
Data Analysis
A custom-designed Labview (National Instruments, Austin, TX, USA) force plate analysis program was used to calculate the variables of interest. Initiation of the jump movement was defined as the point where the force-time curve dropped below a threshold of 2.5% bodyweight. The end of the jump was calculated from when the force dropped to zero, and the difference between the initiation threshold and zero force was termed the GCT. To calculate velocity and displacement of the center of mass (COM), the acceleration-time curve obtained from the force-time data was numerically integrated using the Simpson method (11). The area under the force-time curve represented impulse, and effects caused by gravitational acceleration were removed from total impulse to quantify net impulse. Takeoff velocity was then calculated from the impulse-momentum relationship, and an equation of constant acceleration (takeoff velocity^2/2*gravity) was used to estimate jump height (9).

The GCT was divided into an eccentric phase (i.e., countermovement phase) and a concentric phase (i.e., propulsive phase). The start of the concentric phase was determined when velocity became positive, which corresponded to the minimum displacement of the COM (9). The eccentric GCT, the maximal eccentric velocity (i.e., downward velocity), and the eccentric displacement of the COM (i.e., bottom position of countermovement) were recorded for further analysis. In addition, jump height for the VCMJ and distance jumped for the HCMJ and LCMJ jump were also recorded.

Statistical Analyses
The mean and SD were calculated for all results. Within-trial variability of the 3 trials of the different jumps was quantified using the typical error as a CV from the log-transformed data (15). Then, the 3 trials for each leg of each jump assessment were averaged for an individual subject mean, and subject means were averaged to provide a group mean. A two-way (leg x jump) repeated-measures analysis of variance and Bonferroni post hoc analysis was used to determine significant differences between the eccentric variables and the dominant and nondominant leg and the type of jumps. If no difference existed between the legs, analysis was conducted on the dominant leg only. The relationship between eccentric variables and jump performance (i.e., height, distance) were similar between limbs. It appears that in the absence of instruction, training, and injury, the legs develop very similar eccentric movement patterns irrespective of dominance and nondominance in the healthy population.

Of interest was the degree of variability associated with the eccentric phase without instructions to standardize the jumps in any manner. As intimated previously, it was thought that stretch amplitude (displacement), velocity, and time over which force is applied (eccentric GCT) would affect jump performance. Determining the variability of these measures and their influence on jump performance provides insight into the level of standardization needed during jump assessment. Eccentric GCT, which has been manipulated as a training mode in the vertical fashion (24), appeared to have the lowest variability across the 3 movement types. The between-trial GCT variability was smallest for the VCMJ (8.5% = approximately 0.035 s) and greater for the other 2 types of jumps (10.1–11.7% = approximately 0.068 s). Eccentric displacement appeared to have the greatest variability in the VCMJ and HCMJ (10.6–13.5% = approximately 0.02 m). In terms of peak eccentric velocity, the between-trial GCT variability for peak eccentric velocity was smallest for the VCMJ (8.7% = approximately 0.04 m s^-1) and greater for the other 2 types of jumps (13.0–13.4% = approximately 0.068 m s^-1), demonstrating that the downward acceleration is more consistent during the VCMJ. The higher variability of
the eccentric variables in the LCMJ and HCMJ could be attributed to the fact that force is being applied over a greater time period in the lateral and horizontal directions, and therefore greater variability naturally occurs. Also, it is most likely that the vertical jump is the most common form of jump assessment used when assessing leg extensor qualities, and therefore less variability would be associated with a more practiced movement. Conversely, when the jump performance is of interest, the HCMJ and LCMJ showed a lower variability compared with the jump height of the VCMJ. The typical error as a CV represents the noise associated with the measurement of interest. This noise can be biological (e.g., learning effect, fatigue) or caused by the equipment (14). For the eccentric variables, all the data were recorded with the force plate, and the same mathematical calculus were used. In summary, it appears that there are minimal differences in these eccentric variables between trials, and therefore the accepted practice of asking subjects to self-regulate depth and velocity of the eccentric phase may not be problematic. However, for the jump performances, jump height was determined from the takeoff velocity measured with the force plate, and the distance jumped was measured with a tape measure. It appears that the calculation of jump height from takeoff velocity resulted in greater variability compared with the direct measurement of the distance jumped. Strength and conditioning professionals should be aware that the variability of the measurement could change depending on the method of measurement and need to take into account the typical error when a change in performance is intended to be determined (14).

Significant differences were observed between the 3 types of jumps in the eccentric kinematic variables of interest. The countermovement of the VCMJ was performed at a higher velocity ($p < 0.05$) than the HCMJ (0.15 m·s$^{-1}$) and LCMJ (0.06 m·s$^{-1}$) over a smaller movement amplitude (0.02–0.05 m), which resulted in a significantly shorter eccentric contact time (approximately 0.18 s). During the LCMJ, significantly greater eccentric displacement occurred than during the HCMJ (0.03 m) but at a faster velocity as well (0.09 m·s$^{-1}$). Consequently, no difference in eccentric contact time between the 2 types of jumps was found. It appears from these results that not only do the eccentric phases require different directional force application, but also the kinematics of the eccentric phase are different between jumps. Previous researchers (12,16,21) have found that the magnitude of hip joint flexion was greater in the HCMJ as compared with the VCMJ, resulting in a lower COM at the bottom position, and both the maximal hip and knee flexion occurred later in the HCMJ (12,21). Jones and Caldwell (16) also reported that the COM had unique linear angular momentum at the beginning of the push-off phase depending on the jump performed, which suggested that directional control begins during the countermovement. Similar mechanisms could explain the difference between the LCMJ and the 2 other jumps; however, because of the novelty of this jump, further research needs to be conducted to confirm such a contention. What is apparent is that the eccentric phase of each jump is relatively unique and therefore most likely requires different training strategies for optimization.

Previous studies have reported that GCT, stretch velocity, and amplitude are important determinants of jump performance (3,5–7,20). However, this was not borne out in the sample studied in this article for the VCMJ. It appears that the faster stretch velocities, shorter contact times, and smaller eccentric displacements associated with the VCMJ had no shared variance ($R^2 = 0.001–0.005$) with jump height. However, moderate to large correlations were found between the eccentric peak velocity and the jump performance in the HCMJ and LCMJ ($r = −0.60$ and $−0.54$, respectively) as well as between the eccentric displacement and jump performance in both jumps ($r = 0.57$ and 0.37, respectively). That is, there is a tendency that the deeper the countermovement and faster the stretch velocity, the better the jump performance. Given the work/energy relationship, this intuitively makes sense in that, if force is applied over a greater distance (work), greater energy will result that can be used for the ensuing concentric contraction. Because both the HCMJ and LCMJ are characterized by slower stretch velocities and greater amplitudes and contact times, it may be that the benefits of the countermovement advantage slower SSC activity. This different influence of the countermovement across the jumps reinforces the previous finding that the kinematics of the eccentric phase (countermovement) is relatively unique between jumps and most likely has a differential influence on jump performance.

**Practical Applications**

Data of the current study demonstrated that no standardization of the countermovement is necessary (i.e., low within-trial variability) when performing unilateral countermovement jump in various directions, and therefore practitioners should allow the participants to perform the jump in a natural fashion after familiarization. Because the greatest variability was found with the HCMJ and LCMJ, it is recommended to allow extensive familiarization and learning for these 2 jumps. In the absence of instruction and injury, the legs develop very similar eccentric movement patterns irrespective of dominance and nondominance, and therefore eccentric assessment of 1 limb is sufficient in similar samples, as used in this study. Considering that no leg asymmetries existed in the healthy athletic population, the countermovement pattern could be used as a tool to monitor return to competition by comparing the noninjured and injured limb in a clinical population. In terms of the influence of the eccentric phase, it appears that each of the jumps have different eccentric kinematic strategies as well as directional force application and may need to be trained separately. However, such a contention needs to be investigated by way of longitudinal studies determining the influence of changes in VCMJ performance on, for example, HCMJ and LCMJ performance or vice versa. Finally, eccentric displacement...
and velocities positively influenced horizontal and lateral jump performance; therefore, coaching faster and larger amplitude countermovements appears important if greater jump distances and impulses are desired in the horizontal and lateral planes of motion.

REFERENCES


