

# Validity of a Simple Method for Measuring Force-Velocity-Power Profile in Countermovement Jump

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**Purpose:** To analyze the reliability and validity of a simple computation method to evaluate force ( $F$ ), velocity ( $v$ ), and power ( $P$ ) output during a countermovement jump (CMJ) suitable for use in field conditions and to verify the validity of this computation method to compute the CMJ force-velocity ( $F-v$ ) profile (including unloaded and loaded jumps) in trained athletes. **Methods:** Sixteen high-level male sprinters and jumpers performed maximal CMJs under 6 different load conditions (0–87 kg). A force plate sampling at 1000 Hz was used to record vertical ground-reaction force and derive vertical-displacement data during CMJ trials. For each condition, mean  $F$ ,  $v$ , and  $P$  of the push-off phase were determined from both force-plate data (reference method) and simple computation measures based on body mass, jump height (from flight time), and push-off distance and used to establish the linear  $F-v$  relationship for each individual. **Results:** Mean absolute bias values were 0.9% ( $\pm 1.6\%$ ), 4.7% ( $\pm 6.2\%$ ), 3.7% ( $\pm 4.8\%$ ), and 5% ( $\pm 6.8\%$ ) for  $F$ ,  $v$ ,  $P$ , and slope of the  $F-v$  relationship ( $S_{Fv}$ ), respectively. Both methods showed high correlations for  $F-v$ -profile-related variables ( $r = .985-.991$ ). Finally, all variables computed from the simple method showed high reliability, with ICC  $>.980$  and CV  $<1.0\%$ . **Conclusions:** These results suggest that the simple method presented here is valid and reliable for computing CMJ force, velocity, power, and  $F-v$  profiles in athletes and could be used in practice under field conditions when body mass, push-off distance, and jump height are known.

**Keywords:** jumping, force-velocity relationship, lower-limb explosive performance, resistance training

Lower-limb ballistic movements, aimed at accelerating the body mass as much as possible over 1 repetition of bilateral leg extension, are thought to play a key role in physical performance.<sup>1</sup> Vertical jumps represent the most-used example of this type of movement.<sup>2,3</sup>

The use of devices such as force platforms, linear and rotary position transducers, jump mats, accelerometers, and smartphone applications is now common to assess athletes' neuromuscular capabilities and enable the measurement of many kinetic and kinematic parameters. The force plate is one of the most widely used sports-laboratory measurement tools<sup>4-6</sup> and is considered the gold standard for determining the mechanical outputs of sport movements such as jumping. Force plates are used to measure ground-reaction force, derive the velocity of the center of mass, and calculate the power generated using the impulse-momentum relationships. Individual force-velocity ( $F-v$ ) and power-velocity relationships are usually determined to assess an athlete's mechanical-capabilities profile.<sup>7,8</sup> These relationships describe the changes in external force generation and power output with increasing movement velocity and may be

summarized through 3 typical variables: the theoretical maximal force at null velocity ( $F_0$ ), the maximal power output ( $P_{max}$ ), and the theoretical maximal velocity at which the lower limbs can extend during 1 extension under zero load ( $v_0$ ).<sup>8</sup> The ratio between  $F_0$  and  $v_0$  (ie, the slope of the linear  $F-v$  relationship) characterizes the  $F-v$  profile of the neuromuscular system.<sup>8</sup> It has been shown that this  $F-v$  profile affects maximum impulse performances independently from the large effect of  $P_{max}$ , with the existence of an individually optimal  $F-v$  profile.<sup>7-9</sup> This optimal  $F-v$  profile ( $S_{Fv,opt}$ ), shown in squat jump (SJ) or countermovement jump (CMJ), corresponds to the best balance between external force and maximal velocity capabilities.<sup>7-9</sup> Therefore, an appropriate determination of the  $F-v$  relationship seems to be crucial to quantify the mechanical capabilities of the lower limbs. However, these devices are expensive and thus not available to many athletes and practitioners. In addition, data processing is usually necessary after the collection of instantaneous force-time data, which can be time consuming. To address these issues, a simple method for evaluating force, velocity, and power output during an SJ has been validated by Samozino et al.<sup>10</sup> However, the use of this method to determine individual  $F-v$  and power-velocity relationships in field conditions has not yet been examined during unloaded and loaded CMJs.

The aforementioned computation method has been validated for determining the  $F-v$  profile in ballistic actions without countermovement.<sup>8</sup> However, the validity of the simple computation method proposed for the SJ<sup>10</sup> for assessing the  $F-v$  profile has not been confirmed for the CMJ. Therefore, our aims were to analyze the reliability and validity of a simple computation method to evaluate force, velocity, and power output during a CMJ in field conditions and to verify the validity of this computation method to evaluate the CMJ  $F-v$  profile (including unloaded and loaded jumps) in trained athletes.

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## Methods

### Subjects

Sixteen trained male Spanish national- and international-level sprinters and jumpers age  $23.1 \pm 4.1$  years, body mass  $76.3 \pm 6.4$  kg, and height  $1.81 \pm 0.06$  m gave their written informed consent to participate in this study, which was approved by the local ethical committee of the University of Pablo de Olavide (Seville, Spain) and conducted in agreement with the Declaration of Helsinki. No physical limitations or musculoskeletal injuries that could affect testing were reported. All athletes had a strength-training background ranging from 4 to more than 6 years and were highly trained and familiar with the testing exercises.

### Experimental Design

The current study used a cross-sectional experimental design. All tests were conducted at the same time of day, from 5 PM to 9 PM. Each subject underwent anthropometric assessment and performed unloaded and loaded CMJs on a force plate to determine the individual  $F$ - $v$  and force-power-output relationships. The mean vertical force developed by the lower limbs during push-off ( $F$ ), the corresponding mean vertical velocity ( $v$ ), the mean power ( $P$ ), and the  $F$ - $v$  relationships were determined using both the force plate and the simple method for each trial.

### Testing Procedures

**Jump Test.** At the beginning of the testing session, the anthropometric measurements (body mass, stature, and height push-off [ $h_{PO}$ ]) were performed. After a standardized warm-up consisting of 10 minutes of jogging on a treadmill, dynamic stretching, and preparatory vertical jumps, participants performed maximal CMJs under different loading conditions (without loads and against 5 extra loads ranging from 17 to 87 kg in a randomized order) to determine individual  $F$ - $v$  relationships in CMJ. Before each jump, participants were instructed to stand up straight and still on the center of the force plate with their hands on their hips for unloaded conditions and on the bar (17 kg) for loaded jumps; this hand position remained the same during the entire movement. From this position, participants initiated a downward movement to reach a squatting position with a knee angle of  $\sim 90^\circ$  (this angle was individual for each subject), followed immediately by a jump to maximum height. Although subjects were expert in the exercise, verbal instructions were given to control the degree of squatting achieved. The vertical distance covered by the center of mass during push-off ( $h_{PO}$ ) was recorded from the force plate for further analysis. At landing, subjects were asked to touch down with the same leg position as when they took off, that is, with extended legs and maximal foot plantar flexion. If all these requirements were not met, the trial was repeated. Two valid trials were performed with each load with 2 minutes recovery between trials and 4 to 5 minutes between load conditions to minimize the likelihood of fatigue.

#### Equipment and Data Acquisition for the Force-Plate Method.

The test was performed in a Smith machine (Multipower Fitness Line, Peroga, Spain) that allowed a smooth vertical displacement of the bar along a fixed vertical path. A standard force plate (Bertec, Type 4060-15, Bertec Corp, Columbus, OH, USA) was used to sample vertical ground-reaction force at 1000 Hz. This device was interfaced with an analog-to-digital converter MP100.2.0 (Biopac Systems Inc, Santa Barbara, CA, USA) connected to a personal

computer. Customized software (Isonet, Madrid, Spain) provided real-time collection and visualization of  $F$ ,  $v$ , and  $P$  output data from the best trial of each condition, determined from the averages of instantaneous values recorded over the entire push-off phase. The vertical velocity of the body's center of mass was obtained from the integration over time of the vertical-acceleration signal obtained from force-plate measurements. The instantaneous vertical power was the product of force and velocity at each instant. The push-off began when the velocity signal increased and ended when the force signal at takeoff fell to zero. In addition,  $h_{PO}$  was determined from integration of the velocity signal over time.<sup>8</sup> For practical reasons, and because jump height can be easily and very accurately obtained with a contact mat and even using an iPhone or iPad app<sup>11,12</sup> that measures flight time, jump height was directly measured from flight-time data derived from the force signal.

### Computation Method

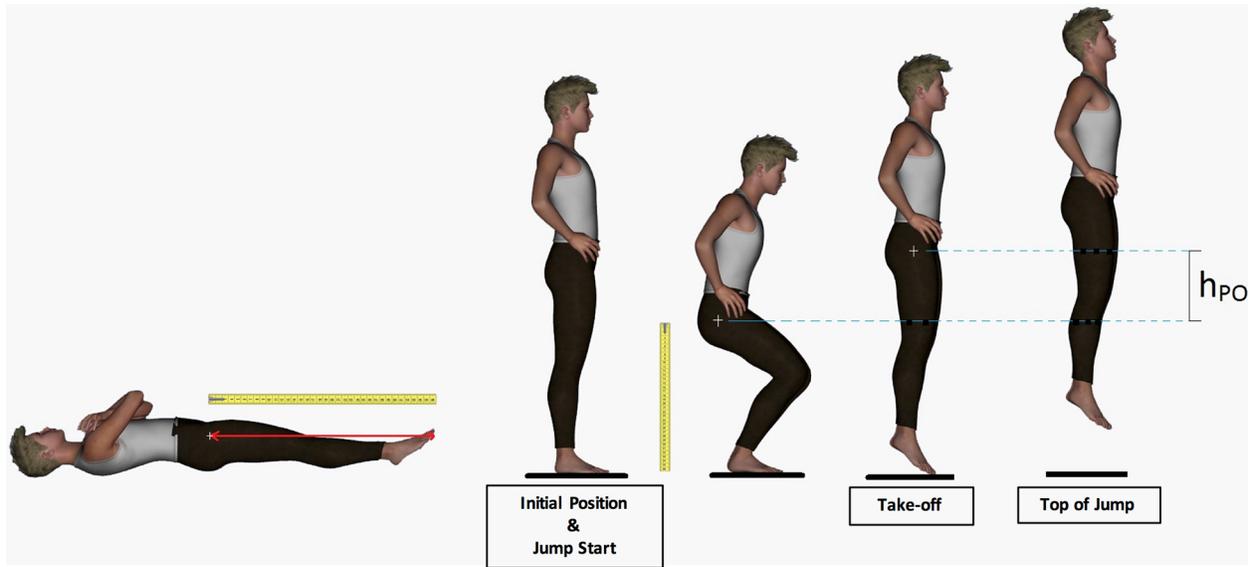
As has been previously reported,<sup>10</sup> it is possible to calculate the values of  $F$ ,  $v$ , and  $P$  during a jump from 3 simple variables; body mass ( $m$ ), jump height ( $h$ ), and push-off distance ( $h_{PO}$ ). For a proper measurement of the  $h_{PO}$ , the subject was placed in a squat position, which was similar to the beginning of the concentric phase of a CMJ and the heels on the floor. The vertical distance between the ground and the right leg's greater trochanter was measured at an approximately  $90^\circ$  knee-angle squat position, set using a square ( $h_S$  in Figure 1) for each subject.  $h_{PO}$  corresponded to the lower limb's length change between the starting position and the moment of takeoff. For convenience, it was assumed that changes in the relative vertical positions of the greater trochanter and center of mass during a jump could be neglected.<sup>10</sup> The value of  $h_{PO}$  was then calculated as the difference between  $h_S$  and the extended lower-limb length with maximal foot plantar flexion (distance from greater trochanter to tiptoe).  $h$  was determined from flight time ( $t_F$ ), applying the fundamental laws of dynamics<sup>13</sup> with  $t_F$  measured from the ground-reaction-force time signal:  $h = (1/8)gt_F^2$ . Thus, as previously computed for SJ,<sup>10</sup>  $\bar{F} = mg[(h/h_{PO}) + 1]$ ,  $\bar{v} = \sqrt{gh/2}$ , and  $\bar{P} = mg[(h/h_{PO}) + 1]\sqrt{gh/2}$ , where  $m$  is the body mass in unloaded condition and body mass of the system (subject + additional load) in loaded conditions,  $g$  is the gravitational acceleration,  $h$  is the jump height, and  $h_{PO}$  is the vertical push-off distance.

### $F$ - $v$ Relationships During Countermovement Jumps

As previously suggested,<sup>8,14-16</sup>  $F$ - $v$  relationships were determined by least-squares linear regressions. The best trial with each load condition was used for analysis. Given that power-velocity relationships are derived from the product of force and velocity, they were described by second-degree polynomial functions.  $F$ - $v$  curves were extrapolated to obtain  $F_0$  (in N or N/kg) and  $v_0$  (in m/s), which, respectively, correspond to the intercepts of the  $F$ - $v$  curve with the force and velocity axis. The  $F$ - $v$  profile was computed as the slope of the  $F$ - $v$  linear relationship ( $S_{Fv}$ , in  $N \cdot s^{-1} \cdot kg^{-1} \cdot m^{-1}$ ).<sup>8</sup> Values of  $P_{max}$  (in W or W/kg) were determined as  $P_{max} = F_0 \times v_0/4$ .<sup>8,17</sup>

### Comparison of the 2 Methods and Statistical Analysis

All data are presented as mean  $\pm$  SD. Normality was checked with the Shapiro-Wilk test before analyses. Test-retest absolute reliability was measured by the standard error of measurement



**Figure 1** — The 3 key positions during a vertical countermovement jump and the 3 distances used in the proposed computations.

(SEM), which was expressed in relative terms through the coefficient of variation (CV), whereas relative reliability was assessed by the intraclass correlation coefficients and confidence interval (ICC, 95%CI) calculated using the 1-way random-effects model. The SEM was calculated as the root mean square of total mean-square intrasubject variation. In the sport-science field it has been suggested that CV values lower than 10% are acceptable, and ICC values greater than .90 are high, .80 to .90 moderate, and lower than .80 questionable.<sup>18</sup> Concurrent validity was assessed using different procedures. Linear regressions and Bland-Altman analyses<sup>19</sup> were performed on the best trial of each load to compare the  $F$ ,  $v$ , and  $P$  values obtained with the 2 methods. The difference between the 2 methods (systematic bias) was computed for these parameters and tested for each trial using a paired-sample  $t$  test.<sup>20</sup> ICC values (relative validity), between-methods differences in means (absolute validity in raw units and %), and CVs (absolute validity in %) were calculated. The magnitude of correlation was assessed with the following thresholds: <.10, trivial; .10 to .30, small; .30 to .50, moderate; .50 to .70, large; .70 to .90, very large; and .90 to 1.00, almost perfect.<sup>21</sup> For concurrent validity, values greater than .90 are good predictors.<sup>18</sup> For all statistical analyses, a  $P$  value of .05 was accepted as the level of significance.

## Results

### Reliability

Between-trials reliability was analyzed. ICC (95% CI) and CV values for each of the kinetic and kinematic variables analyzed are reported in Table 1. A high reliability was found for all variables (ICC > .980 and CV < 1.0%); in particular,  $h_{PO}$  showed an ICC of .998 (95% CI .995–.999) and CV of 0.4%.

### Validity

Mean  $\pm$  SD of each kinetic and kinematic variable obtained from the 2 methods are presented in Table 2. These data were obtained from the best trial against each loading condition. The paired-sample  $t$

**Table 1** Relative and Absolute Reproducibility of Kinetic and Kinematic Variables Analyzed During Countermovement Jump, N = 16

	ICC (95% CI)	CV (%)
From force plate		
$h_{PO}$	.998 (.995–.999)	0.4
$h$	1.000 (.999–1.000)	0.2
$F$	.999 (.998–1.000)	0.3
$V$	.985 (.959–.995)	0.7
$P$	1.000 (.999–1.000)	0.2
From simple method		
$F$	1.000 (.999–1.000)	0.2
$V$	1.000 (.999–1.000)	0.1
$P$	1.000 (.999–1.000)	0.3

Abbreviations: ICC, intraclass correlation coefficient; CI, confidence interval; CV, coefficient of variation;  $h_{PO}$ , displacement of the center of mass from the beginning of concentric phase to the time of takeoff;  $h$ , jump height calculated from aerial time measured from force plate;  $F$ , mean vertical force developed by the lower limbs during push-off;  $V$ , mean vertical velocity developed by the lower limbs during push-off;  $P$ , mean power output developed by the lower limbs during push-off.

test did not show significant differences between the 2 methods for  $F$ ,  $v$ , and  $P$  parameters. However,  $v_0$ ,  $P_{max}$ , and  $S_{FV}$  values showed significant ( $P < .05$ ) differences between methods (Table 2). When the relationships between both methods were individually adjusted, almost perfect relationships were observed for  $F$  ( $r = .985–.999$ ),  $v$  ( $r = .985–.999$ ), and  $P$  ( $r = .994–.999$ ). When considering all subjects,  $F$ ,  $v$ ,  $P$ ,  $F_0$ ,  $v_0$ ,  $P_{max}$ , and  $S_{FV}$  variables obtained from the 2 trials were almost perfectly correlated ( $r = .985–.997$ ,  $P < .001$ , Table 2). Slopes and y-intercept values of the linear regressions were not significantly different from one and zero, respectively, except for  $F_0$  and  $S_{FV}$  (Table 2).

**Table 2 Standard Deviation, Mean Bias (%) and Relationships Between Both Methods for Mean Force, Velocity, and Power Output, and Force–Velocity Relationships**

	Force-plate method, mean $\pm$ SD	Computation method, mean $\pm$ SD	Mean bias (%), mean $\pm$ SD	Pearson correlation coefficient ( <i>r</i> )	Slope of the linear- regression line <sup>a</sup>	y-intercept of the linear- regression line
Computation method						
<i>F</i> (N)	1758 $\pm$ 131	1769 $\pm$ 129	0.0 $\pm$ 1.0	.995*	0.98	35
<i>v</i> (m/s)	1.61 $\pm$ 0.07	1.61 $\pm$ 0.07	0.0 $\pm$ 0.0	.996*	0.97	0.04
<i>P</i> (W)	2839 $\pm$ 319	2847 $\pm$ 317	0.2 $\pm$ 1.0	.997*	1.02	–47
<i>F–v</i> relationships						
<i>F</i> <sub>0</sub> (N)	2547 $\pm$ 236	2541 $\pm$ 253	0.9 $\pm$ 1.6	.989*	1.07	–196 <sup>b</sup>
<i>v</i> <sub>0</sub> (m/s)	5.27 $\pm$ 1.69	5.59 $\pm$ 2.13†	4.7 $\pm$ 6.2	.991*	1.25	–0.99
<i>P</i> <sub>max</sub> (W)	3320 $\pm$ 839	3464 $\pm$ 1017†	3.7 $\pm$ 4.8	.989*	1.20	–518
<i>S</i> <sub><i>Fv</i></sub> (N · s <sup>–1</sup> · m <sup>–1</sup> )	–528 $\pm$ 153	–507 $\pm$ 169†	5.0 $\pm$ 6.8	.985*	1.05	46 <sup>b</sup>

Abbreviations: *F*, mean vertical force developed by the lower limbs during push-off; *v*, mean vertical velocity developed by the lower limbs during push-off; *P*, mean power output developed by the lower limbs during push-off; *F*<sub>0</sub>, the theoretical maximal force at null velocity; *v*<sub>0</sub>, the theoretical maximal velocity at which lower limbs can extend during 1 extension under zero load; *P*<sub>max</sub>, maximal power output against different loading conditions; *S*<sub>*Fv*</sub>, slope of the linear force–velocity relationship

\**P* < .001. †Significant differences between methods (*P* < .05).

<sup>a</sup> Not significantly different from unity. <sup>b</sup> Significantly different from zero.

The Bland–Altman plots for *F*, *v*, and *P* are presented in Figure 2. The mean biases between the 2 methods were 0.2  $\pm$  18.1 N, 0.01  $\pm$  0.02 m/s, and 4.5  $\pm$  22.5 W for *F*, *v*, and *P*, respectively. The Bland–Altman plots for *F*<sub>0</sub>, *v*<sub>0</sub>, *P*<sub>max</sub>, and *S*<sub>*Fv*</sub> are presented in Figure 3. The mean biases between the 2 methods were –21.9  $\pm$  79.3 N, 0.31  $\pm$  1.00 m/s, 144.2  $\pm$  441.9 W, and 20.7  $\pm$  56.7 N · m<sup>–1</sup> · s<sup>–1</sup> for *F*<sub>0</sub>, *v*<sub>0</sub>, *P*<sub>max</sub>, and *S*<sub>*Fv*</sub>, respectively. Expressed relative to the mean values obtained with the force-plate method, these biases were 0.0%  $\pm$  1.0%, 0.0%  $\pm$  0.0%, and 0.2%  $\pm$  1.0%, respectively (Table 2), and 0.9%  $\pm$  1.6%, 4.7%  $\pm$  6.2%, 3.7%  $\pm$  4.8%, and 5.0%  $\pm$  6.8% for *F*<sub>0</sub>, *v*<sub>0</sub>, *P*<sub>max</sub>, and *S*<sub>*Fv*</sub>, respectively (Table 2).

The ICC and CV values describing the concurrent validity of kinetic and kinematic parameters computed from the simple method against the force plate are reported in Table 3. The relative (ICC) concurrent validity of the simple method was very good overall, with ICCs of .990  $\pm$  .009 (range .977–.998), and there was good absolute concurrent validity, with CVs of 3.2%  $\pm$  2.8% (range 0.7–7.6%).

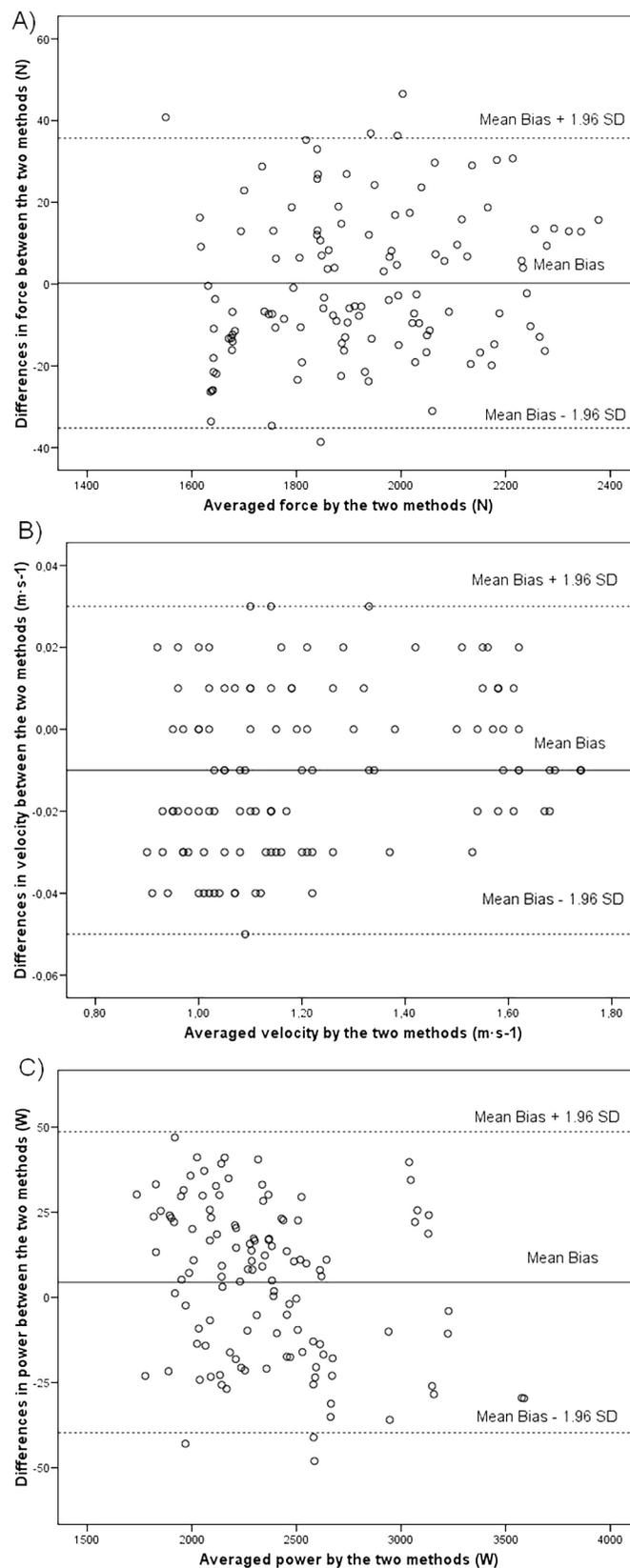
## Discussion

The main findings of this study were that the simple method tested is valid for evaluating force, velocity, and power output during a CMJ based on only 3 simple parameters (body mass, jump height, and push-off distance), and this computation method is also valid for assessing the *F–v* profile in CMJs in elite athletes, although these parameters showed slightly higher bias (<6%) than those observed for force, velocity, and power output in each jump (<1%). In addition, *F*, *V*, *P*, and *h*<sub>PO</sub> showed high reliability with ICC > .980 and CV < 1.0%. The simple computation method proposed here might offer an inexpensive and easy alternative to assess CMJ performance and individualized *F–v* profile without the need of expensive technology such as force plates or position transducers. However, *h*<sub>5</sub> cannot be measured and set along with the starting position immediately before the jump, as occurs for SJ. The *h*<sub>5</sub> variable influences *h*<sub>PO</sub>, which plays a key role in the computations performed from the simple method. However, *h*<sub>PO</sub> showed very high stability (reliability) values

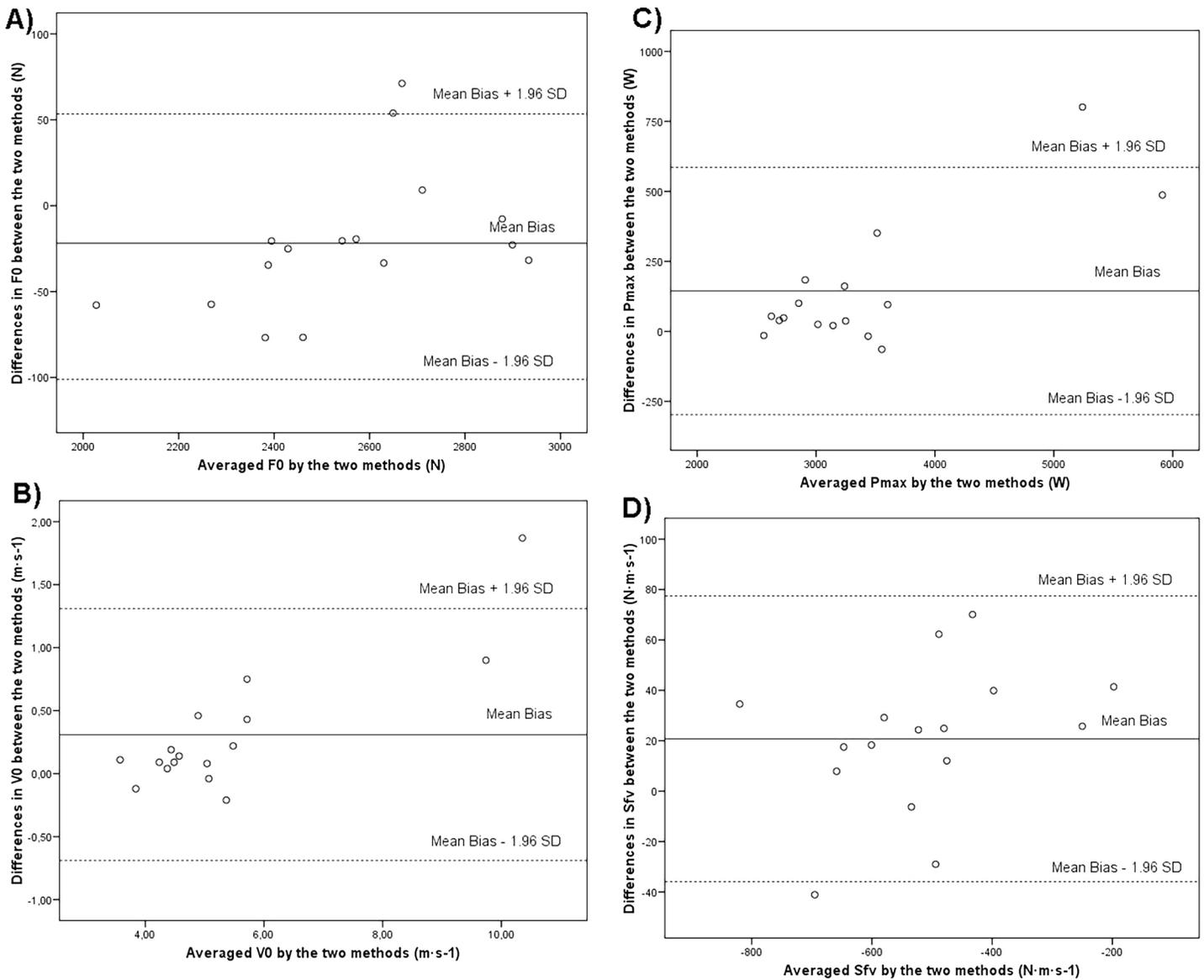
in the trials using the force plate (ICC .998, 95% CI .995–.999, and CV 0.4%). Thus, in experienced athletes, *h*<sub>PO</sub> is reproducible between trials, so there should not be substantial errors in *F*, *V*, and *P* estimations when using the simple method. Therefore, the proposed method allows accurate assessment of lower-limb force, velocity, and power during unloaded and loaded CMJs in field conditions, using only 3 simple parameters (body mass, jump height, and *h*<sub>PO</sub>).

Objectively assessing performance to individualize training programs is one of the main problems faced by strength and conditioning coaches. The search for a simple field evaluation method has given rise to major concerns in the scientific literature for several decades.<sup>10,22–24</sup> The equations used for this study have been previously applied in unloaded SJ conditions.<sup>10,24</sup> These equations come from computations based on fundamental laws of mechanics, and no postulates in conflict with reality were required. That said, the biases introduced by the simplifications and approximations associated with this approach were shown to be very low and trivial (average of 0.1%, range 0.0–0.2%) for *F*, *V*, and *P* computed using both unloaded and loaded CMJs, which supports the approach's validity. These results extend experimental conclusions drawn for pure concentric SJs<sup>8,10</sup> to an exercise (CMJ) that is more frequently used and suitable in sports training and testing.<sup>25</sup> The only basic postulates admitted here were those inherent to all studies applying Newton's laws to the whole human body considered as a system represented by its center of mass.<sup>7–10,24,26,27</sup> Some of these assumptions include equality between average force over distance and average force over time and average power being equal to the product of average force and average velocity.

A measurement method is considered valid if it measures what it intends to measure. This implies that this method is suitable and reliable. The suitability of the proposed method is supported by the power values obtained, which are in accordance with a previous study<sup>10</sup> that considered SJ. The relationships observed between the values obtained by the proposed method versus those measured by the force plate for *F*, *V*, and *P* were *r* = .995 to .997 (*P* < .001, Table 2). The magnitude of these relationships was even higher than those observed by Samozino et al<sup>10</sup> for *F*, *V*, and *P* in SJ (*r* = .96–.98).



**Figure 2** — Bland-Altman plot of differences between the force-plate and computation methods for (A) force, (B) velocity, and (C) power. Upper and lower horizontal dotted lines represent the limits of agreement (mean  $\pm$  1.96 SD of the difference between methods).



**Figure 3** — Bland-Altman plot of differences between the force-plate and computation methods for (A) the theoretical maximal force at null velocity ( $F_0$ ), (B) the theoretical maximal velocity under zero load ( $v_0$ ), (C) the theoretical maximal power output ( $P_{max}$ ), and (D) the slope of the linear  $F-v$  relationship ( $S_{Fv}$ ). Upper and lower horizontal dotted lines represent the limits of agreement (mean  $\pm$  1.96 SD of the difference between methods).

Moreover, the mean bias and the limits of agreement presented in Bland-Altman plots (Figure 2) showed great accuracy for  $F$ ,  $V$ , and  $P$  parameters during CMJ. The difference between data measured by force plate and those obtained from this computation method appears to be unaffected by the magnitude of the  $F$ ,  $V$ , and  $P$  parameters, which is manifested by the negligible association shown in the Bland-Altman plot (mean biases between the 2 methods were  $0.2 \pm 18.1$  N,  $0.01 \pm 0.02$  m/s, and  $4.5 \pm 22.5$  W for  $F$ ,  $v$ , and  $P$ , respectively, Figure 2). The absolute bias is a key parameter in synthesizing the validity and the accuracy of measurement method, since it considers both systematic bias and random errors (standard deviation of the differences). This represents the mean error in each measurement. In the current study, the absolute bias values were less than 1% for  $F$ ,  $V$ , and  $P$ . These absolute bias values are even lower than those reported previously for these parameters (3%) when com-

paring the same computation method with force-plate measurements during a concentric-only jump.<sup>10</sup> This may be because the CMJ is a more natural and more practiced exercise than SJ. Furthermore, very high concurrent validity was shown for  $F$ ,  $V$ , and  $P$  ( $ICC > .997$  and  $CV < 1.5\%$ ) and for theoretical maximal values of  $F$ ,  $V$ ,  $P$ , and  $S_{Fv}$  ( $ICC > .970$  and  $CV < 8.0\%$ ). Thus, the current study demonstrates an accurate and reproducible simple field method to evaluate force, velocity, and power output of lower-limb extensor muscles during a specific jump test (CMJ) with a precision similar to that obtained with specific, more costly, and less practical laboratory ergometers.

In addition to analyzing isolated SJs or CMJs, determining the  $F-v$  mechanical profile of the lower-limb neuromuscular system might help maximize neuromuscular performance in field conditions.<sup>7-9</sup> The current study supports the validity of this simple method for computing the  $F-v$  profile during a CMJ test, which is a

**Table 3 Relative and Absolute Concurrent Validity of Kinetic and Kinematic Variables Computed From Simple Method**

	ICC (95% CI)	CV (%)
Computation method		
$F$ (N)	.998 (.997–.998)	0.7
$v$ (m/s)	.998 (.997–.998)	1.4
$P$ (W)	.998 (.998–.999)	0.9
$F$ - $v$ relationships		
$F_0$ (N)	.991 (.976–.997)	1.2
$v_0$ (m/s)	.977 (.935–.992)	7.6
$P_{\max}$ (W)	.980 (.944–.993)	5.5
$S_{Fv}$ (N · s <sup>-1</sup> · m <sup>-1</sup> )	.988 (.966–.996)	4.8

Abbreviations: ICC, intraclass correlation coefficient; CI, confidence interval; CV, coefficient of variation;  $F$ , mean vertical force developed by the lower limbs during push-off;  $v$ , mean vertical velocity developed by the lower limbs during push-off;  $P$ , mean power output developed by the lower limbs during push-off;  $F_0$ , the theoretical maximal force at null velocity;  $v_0$ , the theoretical maximal velocity at which lower limbs can extend during one extension under zero load;  $P_{\max}$ , Maximal power output against different loading conditions;  $S_{Fv}$ , slope of the linear force-velocity relationship.

commonly used exercise in sports training and testing and only had been validated during pure concentric jumps.<sup>8</sup> Although  $v_0$ ,  $P_{\max}$ , and  $S_{Fv}$  values showed significant differences between methods, all these parameters showed low absolute biases (ranging from 1% to 5%). These values are similar to those previously reported for these variables measured during lower-limb maximal extensions without previous countermovement.<sup>8</sup> Both methods also showed high correlations for  $F_0$ ,  $v_0$ ,  $P_{\max}$ , and  $S_{Fv}$  variables ( $r = .985$ – $.991$ , Table 2). In addition, the Bland-Altman plots showed low bias between the 2 methods (Figure 3), although in all the analyses performed, these theoretical variables ( $F_0$ ,  $v_0$ ,  $P_{\max}$ , and  $S_{Fv}$ ) showed greater bias and lower validity values than those computed for each jump ( $F$ ,  $V$ ,  $P$ ). A plausible explanation for these results might be that the theoretical variables are estimations extrapolated from the  $F$ ,  $V$ , and  $P$ , which are also estimated. For this reason the errors might be cumulative, decreasing the validity in these parameters. Finally, all variables computed from the simple method showed high reliability, with ICC  $>.980$  and CV  $<1.0\%$  (Table 1). These results support the validity and reliability of the proposed theoretical approach and simple method to compute  $F$ - $v$  profiles in highly trained athletes during CMJs.

The main limitation of this method is the assumption that  $h_{PO}$  is the same as that computed before the jump. However,  $h_{PO}$  showed high reproducibility between trials (ICC .998, 95% CI .995–.999, and CV 0.4%). Therefore, there should not be substantial errors in  $F$ ,  $V$ , and  $P$  estimations due to  $h_{PO}$  measurements when using the simple method presented here. In this sense, it is important to note that  $h_{PO}$  is reliable and constant for a given subject, and what is more important is that the computation of  $h_{PO}$  is individual and consistent between trials. Assuming there might be interindividual differences in the adjustment of CMJ depth when targeting a 90° knee angle, we use each individual's own  $h_{PO}$  for the most comfortable CMJ depth with an angle close to 90°, and make sure that each subject

reaches his or her own CMJ depth during the jump trials for a correct computation of the  $F$ - $v$  profile.

## Practical Applications and Conclusions

In conclusion, the accuracy and reliability of the proposed theoretical computations were in line with those observed when using laboratory ergometers such as force plates. Therefore, the proposed method, based on only 3 simple parameters (body mass, jump height, and  $h_{PO}$ ), allows accurate assessment of lower-limb force, velocity, and power properties during unloaded and loaded CMJs in field conditions. This simple method allows coaches and practitioners to identify individual  $P_{\max}$  and optimal  $F$ - $v$  profiles to maximize CMJ performance in field conditions. These findings extend those previously observed for concentric-only SJ<sup>8,10</sup> to CMJ, which is more frequently used in sports training and testing.

Due to the difficulty of accessing elite athletes to conduct laboratory measurements, the ease of measuring biomechanical parameters in these subjects has scientific interest and direct practical applications. A recent study showed excellent reliability (ICC = .997, CV = 3.4%) and excellent agreement with height measured using a force plate (ICC = .997) for an iPhone application (My Jump app).<sup>11,12</sup> Thus, the simple computation method and My Jump app might be a low-cost, easy-to-use application to assess CMJ performance (force, velocity, and power). These findings could help coaches make evidence-based practice decisions by monitoring the  $F$ - $v$  profile of athletes' lower limbs, which characterizes the ratio between their maximal force and their maximal velocity capabilities. Coaches could use this method to quantify individual athlete's  $P_{\max}$  and  $F$ - $v$  profiles and individualize their training regimens accordingly.<sup>28</sup>

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