Evaluating Upper-Body Strength and Power From a Single Test: The Ballistic Push-up

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Abstract

Wang, R, Hoffman, JR, Sadres, E, Bartolomei, S, Muddle, TWD, Fukuda, DH, and Stout, JR. Evaluating upper-body strength and power from a single test: the ballistic push-up. J Strength Cond Res 31(5): 1338–1345, 2017—The purpose of this study was to examine the reliability of the ballistic push-up (BPU) exercise and to develop a prediction model for both maximal strength (1 repetition maximum [1RM]) in the bench press exercise and upper-body power. Sixty recreationally active men completed a 1RM bench press and 2 BPU assessments in 3 separate testing sessions. Peak and mean force, peak and mean rate of force development, net impulse, peak velocity, flight time, and peak and mean power were determined. Intraclass correlation coefficients were used to examine the reliability of the BPU. Stepwise linear regression was used to develop 1RM bench press and power prediction equations. Intraclass correlation coefficient’s ranged from 0.849 to 0.971 for the BPU measurements. Multiple regression analysis provided the following 1RM bench press prediction equation: 1RM = 0.31 × Mean Force – 1.64 × Body Mass + 0.70 (R² = 0.837, standard error of the estimate [SEE] = 11 kg); time-based power prediction equation: Peak Power = 11.0 × Body Mass + 2012.3 × Flight Time – 338.0 (R² = 0.658, SEE = 150 W), Mean Power = 6.7 × Body Mass + 1004.4 × Flight Time – 224.6 (R² = 0.664, SEE = 82 W); and velocity-based power prediction equation: Peak Power = 8.1 × Body Mass + 818.6 × Peak Velocity – 762.0 (R² = 0.797, SEE = 115 W); Mean Power = 5.2 × Body Mass + 435.9 × Peak Velocity – 467.7 (R² = 0.838, SEE = 57 W). The BPU is a reliable test for both upper-body strength and power. Results indicate that the mean force generated from the BPU can be used to predict 1RM bench press, whereas peak velocity and flight time measured during the BPU can be used to predict upper-body power. These findings support the potential use of the BPU as a valid method to evaluate upper-body strength and power.

Key Words exercise test, athletic performance, force-time curve

Introduction

Both muscular strength and power are important components of athletic performance, and a robust relationship exists between them (31). Muscular strength can be described as the ability of a muscle or group of muscles to produce force. Muscular power is usually expressed as movements involving both strength and velocity factors. The determination of maximal muscular power originates from the force-velocity relationship proposed by Hill (13), who found that an isolated muscle contracts at a velocity inversely proportional to the load. Muscular strength and power are major determinants for many explosive short-duration sporting events (2). Consequently, the assessment of muscular strength and power is imperative for training program design and talent identification purposes.

One of the most traditional methods for determining maximal muscular strength is the 1 repetition maximum (1RM) lift (14). The 1RM squat and bench press are the most frequently used field tests for assessing lower- and upper-body strength, respectively. However, time constraints and maximal testing for untrained individuals may limit the use of 1RM testing in large population groups (33). Mayhew et al. (23) examined the relationship between the number of push-ups completed during 1 minute and 1RM bench press. They found that the number of push-ups performed was not an accurate reflection of upper-body strength in young men. This is not surprising considering that the greater the number of repetitions performed is more indicative of muscular endurance than strength and power. Recently, researchers proposed that a maximal effort, dynamic push-up could be a reliable measure of upper-body power (15). Considering the relationship between strength and power, the estimation of strength based on a maximal effort push-up is possible.
To date, the focus of muscular power testing has been directed to the lower body, with the squat jump and countermovement jump being the primary methods (32). Precise estimation of power often needs sophisticated equipment such as force plates to capture the force-time curve, which impedes its use outside a laboratory. As such, many investigations attempted to estimate vertical jump power from variables such as jump height (1,6,30). The Lewis formula was the first prediction equation proposed to estimate lower-body power from a vertical jump (12,22). Power is calculated from the body mass of the participant and the velocity determined from the jump height. Subsequently, investigations using multiple linear regression analysis developed several power prediction equations that were derived from jump height and body mass (1,6,30). Jump height was initially measured from a jump-and-reach test (12), but it can also be calculated from flight time using a contact mat. Over the past few years, technology such as linear position transducers, accelerometers, and video analysis had been used to measure the mean and peak velocity during the vertical jump (3,10,29), which can also be used to estimate vertical jump power.

There has been only a limited number of investigations that have focused on the evaluation of upper-body muscular power. Two common tests are the seated medicine ball throw (8) and the bench press throw (7). However, there are limitations for each of these assessments. During the seated medicine ball throw, the weight of the ball selected is somewhat arbitrary (8). In regards to the bench press throw, it is generally performed in a Smith machine with at least 2 spotters required to ensure safety or performed in a specially designed device which can be alternatively used to decelerate the barbell during the downward phase (21). Theoretically, the same approach used in vertical jump testing could also allow for the estimation of upper-body power through an upper-body movement such as the ballistic push-up (BPU). The BPU is similar to the vertical jump with regards to a need to overcome the force of gravity exerted on body mass and maximizing force production in a short period. To the best of our knowledge, there are no studies that are known that have investigated this concept. Therefore, the purpose of this study was to examine the reliability of the BPU and to develop a prediction model for both maximal strength in the bench press exercise and upper-body power.

**Methods**

Experimental Approach to the Problem

A cross-sectional design was used. All study participants reported to the Human Performance Laboratory (HPL) on 4 separate occasions. During the first visit, participants were familiarized with the BPU. During the following 3 visits, participants completed a 1RM strength in the bench press exercise and 2 BPU assessments in a random order. In an attempt to eliminate the potential for reduced performance, the participants were asked to refrain from any strenuous physical activity for the previous 48 hours before each HPL visit.

Subjects

Eighty-four recreationally active men who had a mixed athletic background (weightlifting, basketball, soccer, etc.) and were familiar with resistance training volunteered to participate in this investigation. Sixty participants (age: 24.5 ± 4.3 years [range: 18–35]; height: 1.75 ± 0.07 m; body mass: 80.8 ± 13.5 kg) completed all testing and their data were included in the final data analysis. The study was approved by the University’s Institutional Review Board. Testing procedures were fully explained to each participant before obtaining written informed consent from each participant.

Maximal Strength Testing

One-repetition maximum bench press test was performed using methods previously described by Hoffman (14). Before beginning the test, each participant completed a general warm-up that included dynamic movements and 5 minutes of cycling exercise. Each participant then performed 2 warm-up sets using a resistance that was approximately 40–60% and 60–80% of their estimated 1RM, respectively. The third set was the first attempt at the participant’s 1RM. If the set was successfully completed, then weight was added and another set was attempted. If the set was not successfully completed, then the weight was reduced and another set was attempted. A 3–5 minute rest period was provided between each set. The process of adding and removing weight was continued until a 1RM was reached. Attempts that did not meet the range of motion criterion for each exercise, as determined by the researcher, were discarded. The participants were required to lower the bar to their chest before initiating concentric movement. Their grip widths were measured and recorded for later use. All testing was completed under the supervision of a certified strength and conditioning specialist.

The Ballistic Push-up Testing

Participants completed the same warm-up procedure as used for the 1RM bench press. After the warm-up, participants were instructed to adopt a prone position on the force plate (AccuPower; AMTI, Watertown, NY, USA). Participants were also instructed to place their hands in a similar position (e.g., regarding distance apart) as they used during performance of the 1RM bench press. Participants were then asked to move into the starting position by lowering themselves until their chest made contact with the force plate, while keeping their body straight. They were instructed to pause at this position to eliminate the artificial force peak. Once stable in the starting position, participants were then instructed to push as explosively as possible to full arm extension and achieve as much height as possible with hands leaving the force plate and landing with arms slightly bended.
Data Processing
The vertical force-time data for each BPU trial was recorded with a sample rate of 1,000 Hz and then processed using a customized MATLAB (The MathWorks, Inc., Natick, MA, USA) script. As shown in Figure 1, the initial weight was determined from the stable phase in the starting position. Peak force and mean force was defined as the highest and average force achieved during the concentric phase of the push-up movement, respectively. The rate of force development (RFD) was then calculated from the following equation: RFD = ΔForce/ΔTime. The peak RFD was determined as the highest rate of change in force determined across a 20-millisecond sampling window. The mean RFD was determined as the average rate of change in force from the initiation of the push-up movement to the moment of peak force. The net impulse was defined as the area under the force-time curve for values greater than the initial weight within the concentric phase of the push-up movement. Peak velocity was defined as the highest velocity resulted from the accumulation of force over time. Flight time was defined as the time in the air and determined from the vertical force-time data. Peak power and mean power was defined as the highest and average power output resulted from the impulse-momentum relationship, as described previously (9).

Statistical Analyses
The Shapiro-Wilk test was conducted to test normality of each variable. To determine reliability of the BPU, a test-retest reliability analysis was performed using a 2-way random (type, absolute agreement) intraclass correlation coefficient (ICC) calculated for variables recorded during the separate testing sessions. The ICC values higher than 0.75 were considered acceptable (25). SEM was also calculated. Pearson product-moment correlations were calculated between 1RM bench press, body mass, and the BPU measures. Interpretation of the correlation coefficients were based on criteria published by Hopkins et al. (16), indicating that r values of 0.1, 0.3, 0.5, 0.7, and 0.9 represent small, moderate, large, very large, and extremely large relationships, respectively.

The variables (derived from the first BPU testing) which significantly correlated with 1RM bench press were used to develop the 1RM bench press prediction equation by linear regression with stepwise method. Similarly, body mass and flight time were used to derive the time-based prediction equation for peak and mean power, whereas body mass and peak velocity were used to derive the velocity-based prediction equation for peak and mean power. To develop these prediction equations, a two-third split of the data with 40 participants were randomly assigned to the fitting sample. The goodness of fit and precision of the regression equation was evaluated using a multiple coefficient of determination ($R^2$) and the standard error of the estimate (SEE). The remaining 20 participants were used as the validation sample, and their data were applied to the prediction equations to calculate predicted values, which were then compared with the actual measurements using paired samples t tests.

These prediction equations were further validated based on the evaluation of the criterion kinetic-based power measurement versus the power predictions using calculations of the validity coefficient ($r$), constant error (CE), SEE, and total error (TE). Ninety-five percentage limits of agreement (LOA) were also calculated between the kinetic-based measurement and both predictions, according to the procedures described by Bland and Altman (5). A p value less than 0.05 was considered statistically significant for all the statistical analyses. All data were analyzed using SPSS 22.0 (IBM Corp., Armonk, NY, USA). Data are presented as mean ± SD.

RESULTS

Reliability of the Ballistic Push-up Measurements
To quantify the relationship between the BPU variables...
achieved during both trials, ICC values were calculated for the entire sample size. The ICC for peak force, mean force, peak RFD, mean RFD, net impulse, peak velocity, flight time, peak power, and mean power can be observed in Table 1.

### Relationship Between 1 Repetition Maximum Bench Press, Body Mass, and the Ballistic Push-up Measurements
Pearson correlation coefficients between 1RM bench press and body mass, peak force, mean force, peak RFD, mean RFD, net impulse, peak velocity, flight time, peak power, and mean power were 0.718, 0.847, 0.859, 0.654, 0.637, 0.823, 0.465, 0.240, 0.745, and 0.744, respectively (all \( p < 0.001 \) except for flight time, which was \( p = 0.065 \)). In addition, the relationship between flight time and peak (\( r = 0.565 \)) and mean (\( r = 0.521 \)) power, as well as between body mass and peak (\( r = 0.560 \)) and mean (\( r = 0.602 \)) power, were all categorized as large correlations, whereas the relationship between peak velocity and peak (\( r = 0.794 \)) and mean (\( r = 0.789 \)) power were all categorized as very large correlations. Moreover, flight time significantly (\( p < 0.001 \)) correlated with peak velocity (\( r = 0.656 \)).

### Upper-Body Strength Prediction Equation
As indicated by the results of stepwise regression, body mass and mean force were selected to construct the prediction equation for 1RM bench press. The following prediction equation for 1RM bench press was generated:

\[
1\text{RM} = 0.31 \times \text{Mean Force}^2 + 1.64 \times \text{Body mass} + 0.70
\]

(\( R^2 = 0.837, \text{SEE} = 11 \text{ kg} \)). Paired samples \( t \) tests on the validation sample showed no significant (\( p = 0.897 \)) difference between the measured (109.3 ± 26.3 kg) and predicted (109.0 ± 24.0 kg) 1RM bench press. Results from the validity analysis including validity coefficient, CE, \( \text{SEE} \), \( \text{TE} \), and slope and intercept of the linear fit line derived from results of the validation analysis are depicted in Table 2.

### Upper-Body Power Prediction Equation
The following time-based prediction equations were generated:

- Peak Power = 11.0 \times \text{Body Mass} + 2012.3 \times \text{Flight Time}^2 - 338.0 (\( R^2 = 0.658, \text{SEE} = 150 \text{ W} \))
- Mean Power = 6.7 \times \text{Body Mass} + 1004.4 \times \text{Flight Time}^2 - 224.6 (\( R^2 = 0.664, \text{SEE} = 32.1 \text{ W} \))

### Table 1. Reliability statistics for the ballistic push-up measurements.*

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>ICC (95% CI)</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak force (N)</td>
<td>960 ± 188</td>
<td>952 ± 188</td>
<td>0.971 (0.952–0.983)</td>
<td>45</td>
</tr>
<tr>
<td>Mean force (N)</td>
<td>792 ± 140</td>
<td>789 ± 135</td>
<td>0.989 (0.981–0.993)</td>
<td>21</td>
</tr>
<tr>
<td>Peak RFD (N⋅s⁻¹)</td>
<td>4,751 ± 1,862</td>
<td>4,470 ± 1,981</td>
<td>0.849 (0.756–0.908)</td>
<td>1,059</td>
</tr>
<tr>
<td>Mean RFD (N⋅s⁻¹)</td>
<td>2,342 ± 872</td>
<td>2,289 ± 939</td>
<td>0.867 (0.788–0.919)</td>
<td>469</td>
</tr>
<tr>
<td>Net impulse (N⋅s)</td>
<td>81 ± 20</td>
<td>81 ± 20</td>
<td>0.956 (0.928–0.974)</td>
<td>5.9</td>
</tr>
<tr>
<td>Peak velocity (m⋅s⁻¹)</td>
<td>1.30 ± 0.23</td>
<td>1.30 ± 0.22</td>
<td>0.863 (0.781–0.916)</td>
<td>0.12</td>
</tr>
<tr>
<td>Flight time (s)</td>
<td>0.20 ± 0.08</td>
<td>0.21 ± 0.07</td>
<td>0.750 (0.614–0.842)</td>
<td>0.05</td>
</tr>
<tr>
<td>Peak power (W)</td>
<td>939 ± 257</td>
<td>934 ± 239</td>
<td>0.936 (0.895–0.961)</td>
<td>123</td>
</tr>
<tr>
<td>Mean power (W)</td>
<td>516 ± 150</td>
<td>516 ± 144</td>
<td>0.934 (0.891–0.960)</td>
<td>66</td>
</tr>
</tbody>
</table>

*ICC = intraclass correlation coefficient; CI = confidence interval; RFD = rate of force development.

### Table 2. Validation analysis of strength and power prediction equations.*

<table>
<thead>
<tr>
<th>Value (W)</th>
<th>( r )</th>
<th>CE</th>
<th>( \text{SEE} )</th>
<th>( \text{TE} )</th>
<th>Slope</th>
<th>Intercept</th>
</tr>
</thead>
<tbody>
<tr>
<td>1RM(_M)</td>
<td>123.2 ± 20.9</td>
<td>0.852</td>
<td>-3.580</td>
<td>11.2</td>
<td>12.0</td>
<td>0.809</td>
</tr>
<tr>
<td>1RM(_P)</td>
<td>119.6 ± 22.0</td>
<td>0.817</td>
<td>30.022</td>
<td>139.6</td>
<td>136.2</td>
<td>1.058</td>
</tr>
<tr>
<td>PP(_K)</td>
<td>962.1 ± 235.4</td>
<td>0.928</td>
<td>19.936</td>
<td>90.0</td>
<td>87.7</td>
<td>1.012</td>
</tr>
<tr>
<td>PP(_T)</td>
<td>992.1 ± 181.7</td>
<td>0.935</td>
<td>-6.448</td>
<td>50.0</td>
<td>48.5</td>
<td>1.065</td>
</tr>
<tr>
<td>PP(_V)</td>
<td>540.9 ± 101.1</td>
<td>0.852</td>
<td>-3.580</td>
<td>11.2</td>
<td>12.0</td>
<td>0.809</td>
</tr>
<tr>
<td>MP(_K)</td>
<td>541.9 ± 136.9</td>
<td>0.776</td>
<td>-1.015</td>
<td>88.7</td>
<td>84.3</td>
<td>1.051</td>
</tr>
<tr>
<td>MP(_T)</td>
<td>535.5 ± 120.1</td>
<td>0.928</td>
<td>19.936</td>
<td>90.0</td>
<td>87.7</td>
<td>1.012</td>
</tr>
<tr>
<td>MP(_V)</td>
<td>504.9 ± 251.8</td>
<td>0.852</td>
<td>30.022</td>
<td>139.6</td>
<td>136.2</td>
<td>1.058</td>
</tr>
</tbody>
</table>

*CE = constant error; \( \text{SEE} \) = standard error of the estimate; \( \text{TE} \) = total error; 1RM\(_M\) = measured 1RM bench press; 1RM\(_P\) = predicted 1RM bench press; PP\(_K\) = kinetic-based peak power; PP\(_T\) = time-based peak power; PP\(_V\) = velocity-based peak power; MP\(_K\) = kinetic-based mean power; MP\(_T\) = time-based mean power; MP\(_V\) = velocity-based mean power.
Figure 2. Scatter plots (left panel) and Bland-Altman plots (right panel) between the measured and estimated peak and mean power derived from time-based (first and second row) and velocity-based (third and fourth row) equations. Dashed line represents 95% confidence interval.
The following velocity-based prediction equations were generated: Peak Power = 8.1 × Body Mass + 818.6 × Peak Velocity − 762.0 ($R^2 = 0.797, \text{SEE} = 115 W$); Mean Power = 5.2 × Body Mass + 435.9 × Peak Velocity − 467.7 ($R^2 = 0.838, \text{SEE} = 57 W$).

Paired samples t tests on the validation sample showed that the kinetic-based peak and mean power measurements (1012.7 ± 266.6 and 572.7 ± 158.1 W, respectively) were not significantly ($p = 0.286–0.701$) different from the predicted peak and mean power values yielded from the initial time-based (1031.5 ± 221.6 and 564.1 ± 119.6 W, respectively) and velocity-based (1034.7 ± 237.7 and 566.5 ± 131.9 W, respectively) prediction equations.

The scatter plots between the measured and predicted peak and mean power from the final set of prediction equations can be observed in Figure 2. Results from the validity analysis including validity coefficient, CE, SEE, TE, and slope and intercept of the linear fit line derived from results of the validation analysis are depicted in Table 2.

Bland-Altman plots between the measured and predicted peak and mean power from the prediction equations are also depicted in Figure 2. The 95% LOA ranged from −297.1 to 237.0 W and −168.5 to 170.5 W between the kinetic-based and time-based peak and mean power assessments and −191.7 to 151.8 W and −90.2 to 103.1 W between kinetic-based and velocity-based peak and mean power assessments. The regression line indicated that the time-based prediction equation tended to underestimated peak and mean power at lower values and overestimated these measures at higher values, with a trend of positive correlation for both peak ($r = 0.413; p = 0.070$) and mean ($r = 0.438; p = 0.053$) power. No correlation relationship existed for velocity-based peak ($r = 0.228; p = 0.355$) and mean ($r = 0.345; p = 0.136$) power prediction.

**DISCUSSION**

The results of this study indicated that the BPU is a reliable assessment, and that performance measures obtained from the BPU were significantly correlated with the 1RM bench press. Performance in the BPU explained 83.7% of the total variance in the 1RM bench press, and the regression equation developed from body mass and mean force appears to provide an alternative to the 1RM bench press for assessing upper-body strength. Our study also demonstrated that differences in flight time, peak velocity, and body mass were related to differences in peak and mean power output, providing the rationale for the use of these variables (i.e., flight time and peak velocity) as predictors of peak and mean power. Multiple regression analysis demonstrated that both prediction equations produced very good estimates of peak and mean power from the BPU. In time-based prediction equations, body mass and flight time explained 65.8 and 66.4% of the variation in peak and mean power, respectively. As for velocity-based prediction equations, body mass and peak velocity explained 79.7 and 83.8% of the variation in peak and mean power, respectively. Furthermore, the $\text{SEE}$ of velocity-based peak (115 W) and mean (57 W) power predictions appeared to be smaller than that of time-based predictions (150 W for peak power and 82 W for mean power), indicating that velocity-based estimations were more precise than velocity-based estimations.

The reliability of the BPU appeared to be excellent, especially for peak force, mean force, net impulse, peak power, and mean power, meaning that the measurement error is smaller than the individual variability, further suggesting that the measurement error has a very limited effect. The ICC's reported in this study also appeared to be greater than that previously reported by Hrysomallis and Kidgell (17). In their investigation, they recruited 12 untrained men to perform explosive push-ups and reported ICC's of 0.841 and 0.908 for peak and mean force, respectively, which were all less than that observed in this study. In addition, they reported ICC's of 0.865 and 0.958 for mean RFD and impulse, respectively, which were both similar to our results. Our results are also supported by Koch et al. (19), who investigated ground reaction force patterns during plyometric push-ups of varying heights and found ICC's ranging from 0.705 to 0.970 for peak force and 0.904–0.964 for mean RFD.

There have been several other studies that have predicted upper-body strength from repeated push-ups. Dean et al. (11) published the first predictive equation using the product of push-up repetitions and body mass ($R^2 = 0.74, \text{SEE} = 6.3$ kg). In contrast to this study, in which we used a free weight 1RM Olympic barbell bench press to assess maximal strength, the study by Dean et al. (11) used a universal gym machine to test 1RM bench press. A subsequent study by Mayhew et al. (23) explored the relationship between an Olympic barbell 1RM bench press and the product of push-up repetitions and body mass. They reported a significant, positive relationship ($R^2 = 0.50, \text{SEE} = 15.7$ kg) between 1RM bench press and the product of push-up repetitions and body mass. However, others have reported that the Young Men’s Christian Association bench press test is more effective for predicting the 1RM bench press ($R^2 = 0.86, \text{SEE} = 6.0$ kg) than push-up repetitions and body mass ($R^2 = 0.56, \text{SEE} = 10.6$ kg) (18). A recent study examined the relationship between an isometric bench press with the elbows at 90 degrees of extension and 1RM bench press (4). Although a very large positive relationship ($R^2 = 0.86, \text{SEE} = 12.8$ kg) was reported, no cross-validation procedure was conducted.

Several studies have proposed that the BPU could be used as an assessment tool for upper-body muscular power (15,17). However, instead of power, only impulse, peak force,
mean force, and mean RFD were measured in these studies. This is probably because there is no commonly accepted criterion method for upper-body power assessment. This study calculated muscular power of the BPU using the force-time curve and impulse-momentum relationship. The results (ICC = 0.936 and 0.934 for peak and mean power, respectively) indicated that the BPU was a reliable test for the upper-body power assessment. Considering the close relationship between strength and power (31), we examined the relationship between power calculations and the IRM bench press. We demonstrated that both peak and mean power were significantly correlated with the IRM bench press \((r = 0.824\) and 0.797, respectively). This was consistent with results previously reported by Stone et al. (31), indicating that the correlation coefficient between maximal strength and static squat power ranged from 0.750 to 0.938, depending on the relative load. Young et al. (34) examined the reliability of the bench press throw in 24 male athletes (relative IRM bench press: 1.17 \pm 0.25 kg/kg body mass) using 45% of IRM bench press and reported an ICC of 0.890 for peak power. The peak power reported (836 \pm 188 W) was lower than that observed in this study (939 \pm 257 W). This was likely related to participants of this study being stronger and heavier. Our results appear to be similar to those reported by Clemens et al. (8) who compared the mean power output between the bench press with an absolute load of 61.4 kg and a seated medicine ball throw with a 9 kg medicine ball (521 \pm 154 vs. 538 \pm 192 W, respectively).

Previous studies examining power prediction were primarily focused on using the vertical jump height for estimation of lower-body power. Harman et al. (12) tested 17 men on the squat jump and reported an \(R^2\) of 0.88 and 0.77 for peak and mean power, respectively. Their findings were similar to what we found for velocity-based predictions \((R^2 = 0.80\) and 0.84, respectively) and higher than the time-based predictions \((R^2 = 0.66\) and 0.66, respectively). Sayers et al. (30) established peak power prediction equations for squat jump with a \(R^2\) value of 0.88 and an SEE of 372.9 W. We found an SEE of 150 and 115 W for time-based and velocity-based peak power prediction in our study. A possible explanation for this discrepancy may be related to the greater power output observed during the vertical jump than the BPU. When comparing the percentage of SEE accounted for the mean actual measurement of peak power, our results showed an SEE of 15.64 and 11.04% for time-based and velocity-based peak power prediction, which was higher than the result of 9.71% from the study by Sayers et al. (30).

The SEE represents the error between the prediction and actual measurement, whereas the TE combines the error associated with CE and SEE, and therefore provides more information regarding prediction accuracy. It has been suggested that valid predictions exhibit similar SEE and TE (20). In our study, the TE was similar to the SEE for all time-based and velocity-based peak and mean power outputs. Examination of the Bland-Altman plots revealed systematic biases only for time-based but not velocity-based peak and mean power. The 95% LOA for both time-based and velocity-based peak power were considerably lower than that reported by Amonette et al. (1), but similar to the results of Quagliarella et al. (26). Similarly, the 95% LOA for both time-based and velocity-based mean power were markedly smaller than those of previous findings (26). Linear regression analysis demonstrated that there was a trend of systematic bias for time-based peak and mean power, as they underestimated the power at low levels and overestimated it at high levels. However, the bias for velocity-based peak and mean power was not significantly different from zero.

The results of the Bland-Altman analysis agreed with the validation analysis and further demonstrated that velocity-based power prediction equations were more accurate than time-based power prediction equations. As previously discussed, time-based predictions rely on the measurement of flight time or jump height, which could be used to calculate take-off velocity. Such measurements have been criticized for the lack of direct theoretical connection to the power produced during the concentric phase of the vertical jump (12). In contrast from a time-based approach, velocity-based predictions are based on the direct measurement of peak velocity from the propulsive phase, which is the most important phase in explosive movements (28). As depicted in Figure 1, the concentric phase of both the vertical jump and BPU could be divided into the propulsive and braking stages. Peak velocity is achieved at the start of the braking stage. The moment of take-off falls within this braking stage, and therefore, take-off velocity is slower than peak velocity. Although flight time or jump height could be used to estimate take-off velocity, the difference between take-off velocity and peak velocity should not be neglected. These differences vary significantly between individuals and even between trials related to influencing factors such as leg (vertical jump) or arm (push-up) length (24,27). This was confirmed by the correlation coefficient (0.656) between flight time and peak velocity, which indicated that only 43% of the variance in peak velocity could be explained by the change in flight time or take-off velocity.

Although we eliminated the countermovement phase to reduce the variation resulting from a stretch-shortening cycle, we failed to normalize the hand position for the BPU. Therefore, variations in technique may still play a role in influencing the accuracy of power predictions. A limitation of this study is that grip width was not standardized, although the same grip width from IRM bench press test was used for the BPU test. To eliminate the potential effect of differences in grip width, shoulder width should be measured and used for standardization purposes. Besides that, future research is required to determine whether these prediction equations could be used to accurately track changes in strength and power during a training intervention in both men and women.
**PRACTICAL APPLICATIONS**

The proposed upper-body performance testing protocol measures both muscular strength and power from a single test. The use of the BPU may be most appropriate when time and equipment are limited, especially in large group assessments. As for athletes, the nonfatiguing nature of the BPU may allow it to be routinely used to monitor recovery or changes in muscular strength and power during the course of a competitive season or prolonged training cycle. This study also indicated that both time-based and velocity-based methods could be used to predict upper-body power from the BPU, with the velocity-based method appearing to be a better option. Time-based prediction equations and time-based equipment such as timing mats are not recommended to evaluate upper-body power from the BPU because of the presence of systematic bias and large LOA. This finding provides evidence which supports the potential use of an accelerometer or linear position transducer as a valid method, and an alternative to the force plate, to precisely evaluate upper-body power in recreationally trained men.

**REFERENCES**


