ASSESSMENT OF POWER OUTPUT IN JUMP TESTS FOR APPLICANTS TO A
SPORTS SCIENCES DEGREE

Amador J. Lara
Javier Abián
Luis M. Alegre
Luis Jiménez
Xavier Aguado

1Facultad de Ciencias del Deporte, University of Castilla-La Mancha, Toledo, Spain.
2Escuela Superior de Informática, University of Castilla-La Mancha, Ciudad Real, Spain.

Correspondence:
Amador J. Lara
Facultad de Ciencias del Deporte. Universidad de Castilla-La Mancha.
Campus Tecnológico. Antigua Fábrica de Armas.
Avda. Carlos III, s/n. 45071. Toledo, Spain.
Tel.: +34-925-268800 (Ext. 5516)
Fax: +34-925-268846
e-mail: amador.lara@uclm.es

ACKNOWLEDGEMENTS
This study was partially supported by the Ministry of Education of Spain (project DIMOCLUST) and by the Council of Education of Castilla-La Mancha, Spain (project PREDACOM).
ABSTRACT

Background: Our study aimed: 1) to describe the jump performance in a population of male applicants to a faculty of sports sciences, 2) to apply different power equations from the literature to assess their accuracy, and 3) to develop a new regression equation from this population. Methods: The push off phases of the Counter-Movement Jumps (CMJ) on a force platform of 161 applicants (age: 19.0 ± 2.9 years; weight, 70.4 ± 8.3 kg) to a Spanish Faculty of Sports Sciences were recorded and subsequently analyzed. Their hands had to be placed on the hips and the knee angle during the counter movement was not controlled. Each subject had two trials to reach a minimum of 29 cm of jump height, and then two jumps were performed the best trial was analyzed. Multiple regression analysis was performed to develop a new regression equation. Results: Mean jump height was 34.6 ± 4.3 cm, peak vertical force 1663.9 ± 291.1 N and peak power 3524.4 ± 562.0 W. All the equations underestimated power, from 74% (Lewis) to 8% (Sayers). However, there were high and significant correlations between peak power measured on the force platform, and those assessed by the equations. Conclusions: The results of the present study support the development of power equations for specific populations, to achieve more accurate assessments. The power equation from this study [Power = (62.5 x jump height (cm)) + (50.3 x body mass (kg)) – 2184.7] can be used accurately in populations of male physical education students.

Key words: Biomechanics, force platform, power equations, jump performance.
INTRODUCTION

Power output is an essential factor in sport and daily life. It has been widely studied by coaches and researchers, and different ways of measuring and assessing it during running, jumping, cycling and rowing have been developed [1-4]. The ability of generate mechanical power can be utilized as an indicator of muscle fatigue and performance, and the measurement of its changes over time may improve the control during a training process.

Power can be measured externally by different devices, from the mechanical work, or from the force and velocity \[P (W) = F (N) \times v (m/s)\]. Force platforms are accurate instruments to measure power, and they are becoming more accessible [2]. They can be utilized to measure power directly during jump tests. Nowadays, there are portable force platforms that can be used in the field; despite of this, this technology is not easily accessible for most of the coaches and researchers because it is too expensive. The alternative is to make use of simple instruments to measure jump height, and from it, assess power. Different authors [5-10] have proposed equations to calculate power from jump height, body mass and/or height (Table I).

In a recent paper, Canavan and Vescovi proposed a new equation to assess power. This paper has taken criticism from authors like Winter [11] and Bahamonde [12]. Most studies that have proposed new equations to assess power have received some criticism. It is based on factors like the number of subjects utilized to determine the regression equation. For example, the study of Canavan and Vescovi [5] included only 20 subjects, although the appropriate sample size needed to have reliable results should have been 25, according to their own comments. Harman et al. [7] also utilized a small sample, of 17 subjects, but the group of Sayers et al. [9] was greater (108 subjects). The power equations obtained from regression analysis from large sample sizes will be more accurate and applicable to other
populations, so this would be the reason why the Sayers equation is able to predict power better than the other equations, with values very close to those measured on the force platform [13].

A positive point reported by Canavan and Vescovi [5] about their equation was that the standard error of estimate (SEE) was lower than the values reported by Sayers et al. [9]. A lower SEE shows less variability; however, this does not need to mean that the values predicted by the equation will be closer to the actual ones because with a low SEE we could have a narrow range of values but poor accuracy when comparing our data to the actual ones. Another point of criticism from Canavan and Vescovi [5] in the studies of Harman et al. [7] and Sayers et al. [9] is the use of two different jump tests to measure jump height and to assess power. For a valid application of the power equations, power and jump height should have been measured in the same jump, and the jumps have to be maximal, and methodologically correct. Therefore, it would be essential to carry out several familiarization sessions before the tests. Canavan and Vescovi [5] omitted this step, as they described, and they merely demonstrated the jump technique to each subject with two submaximal attempts in the same session.

On the other hand, the assessment of power using equations will always be subjected to some inaccuracy. We agree with Winter [11] when he comments that the most important factor for the jump height is the capability to develop a large acceleration impulse, but the power developed during the push off phase is still measured by coaches and researchers, maybe because it is a different way of assessing the jump performance. Whereas the acceleration impulse is directly related to the jump height [14], the ability of generate peak power does not need to do so [13], and, if it is measured with a force platform we will have accurate data
about the interaction of force and velocity during the push off, as well as other variables, like the lowest position of the center of gravity during the push off phase.

Lara et al. [13] pointed out to the possibility of finding differences in the accuracy of the power equations depending on the level of physical activity of the population studied. Depending on the jump performance, each equation would be more or less accurate in predicting peak power. Therefore, it would be convenient to have specific equations for populations with different jump performance, which would allow us to assess power more precisely, and replace successfully the more accurate methods to measure power.

On the other hand, we have found no studies on jump performance with force platforms in populations of applicants to faculties of sports sciences. Some authors [15-19] have studied samples of physical education students, but only Sayers [9], assessed the power using a regression equation developed from a population of students and athletes, and compared the data with a regression equation developed from the same subjects. The main difference between the present study and Sayers et al. [9] is that they developed a general power equation from a sample of students and athletes, and we believe that the equations have to be developed from and for specific populations, therefore it was hypothesized that the equations will assess power with different accuracy, depending on the jump performance of the population studied. The purposes of this study were firstly, to describe the jump performance in a group of male applicants to a faculty of sports sciences, and secondly, to determine the ability of the power prediction equations to assess the power values in this population. An additional purpose was to develop a new power equation, specific for this population.
MATERIALS AND METHODS

Subjects

The push off phases of the Counter-Movement Jumps (CMJ) of 161 applicants (age: 19.0 ± 2.9 years; weight, 70.4 ± 8.3 kg; mean ± SD) to a Spanish Faculty of Sports Sciences in 2004 were recorded and subsequently analyzed. Written informed consent was obtained from all the subjects, and the study protocol was approved by the institutional research ethics board.

Instrumentation

The jumps were performed on a portable piezoelectric Quattro Jump force platform (Kistler, Winterthur, Switzerland), specifically designed to carry out jump tests. The data were recorded on a computer with a sample rate of 500 Hz.

Protocols

The test protocols were announced four months before the trials, and a demonstration was carried out just before the final test. The subjects were able to warm up at least 10 minutes before the test. Then, their body weight was recorded and they performed the CMJ on the force platform. Their hands had to be placed on the hips during the whole jump (push off, take off, flight and landing) and the knee angle during the counter movement was not controlled. Each subject had two trials to reach a minimum of 29 cm of jump height, and if it was not reached in the first trial, the subjects performed a second CMJ after a one minute rest. When two jumps were performed the best trial was analyzed. This jump height was selected because in previous years at least the 80% of the applicants jumped above this height.

Variables
Jump height was assessed from the flight time, because jump height was obtained immediately, without processing the force-time record. Peak vertical force, force at the transition from eccentric to concentric contraction, peak power \( \text{PP}_{\text{platform}} \) and average power \( \text{AP} \) were analyzed during the push off phase from the integration of the force-time record (Figure 1). Power was also assessed using the equations of Lewis \( \text{PP}_{\text{Lewis}} \), Harman \( \text{PP}_{\text{Harman}} \), Sayers \( \text{PP}_{\text{Sayers}} \) and Canavan and Vescovi \( \text{PP}_{\text{Canavan}} \) (Table I).

Statistics
Statistics were performed with the software package *Statistica for Windows 5.1* (Stasoft, Tulsa, OK, USA). Normality was assessed using the \( W \) of Shapiro-Wilks, the kurtosis and the skeweness, and all of the variables showed normality. Descriptive statistics included means, standard deviations and Pearson product-moment correlations between peak power values from the equations and \( \text{PP}_{\text{platform}} \). One way analysis of variance was used to examine differences between the power values from each method. A \( P \) value of 0.05 was accepted as the level of statistical significance for all analyses. Multiple regression analysis was performed to develop a new regression equation. A minimum of 78 subjects was determined to be an appropriate sample size. A cross validation with 53 subjects was performed to assess predictive accuracy.

RESULTS
Table II shows the variables studied in the jump test, absolute and relative to the body mass (power) and weight (force) and Table III shows the comparison between peak power values measured on the force platform and those assessed by the equations of Lewis, Harman, Sayers and Canavan and Vescovi. Percentage differences between the equations and the values from the force platform are also shown. The greater differences were obtained with the
Lewis equation, which underestimated PP by 74%, while the Sayers equation was the one that gave the closest values to PP_{platform}, with an underestimation of 8%.

The correlations between peak power values from the equations and PP_{platform} are shown in Table IV. The highest correlations were found between PP_{platform} and the power values from the Lewis and Sayers equations (r = 0.90, P < 0.001), whereas the lowest correlation coefficient was found with PP_{Canavan} (r = 0.86, P < 0.001).

The regression equation \[\text{Power} = (62.5 \times \text{jump height (cm)}) + (50.3 \times \text{body mass (kg)}) - 2184.7\] showed a SEE of 246.5 W. Cross validation (n = 53) of the current prediction equation indicated no significant difference (P < 0.05) between PP_{platform} and PP assessed by our power equation.

**DISCUSSION**

The jump heights of our subjects were similar to the physical education students measured by Alegre et al. [15] and Ara et al. [16], but lower than those found in previous studies [17,19,20] and other countries [21,22]. Peak vertical forces were higher than those found by Ara et al. [16] (1236 ± 69 N), while the peak power values found in this study (3936 ± 125 W), and in the ones by López [19] (4043 ± 645 W) and Alegre et al. [15] (51.31 ± 5.30 W/kg), were higher than those found in the present study. The discrepancy between the higher peak vertical force values from our study and the lower peak power could be explained because power is a product of force and velocity, and the subjects of the present study might have been developing their peak power at lower velocity than in Ara et al. [16]. The differences in the utilization of contractile force and velocity during the push off phases
of the jumps could explain why the equations are more accurate when they are applied on populations similar to those from they have been developed.

There were high and significant correlations (from $r = 0.86$ and $0.90$, $P < 0.001$) between $PP_{platform}$ and those assessed by each of the four power equations. The lowest correlation coefficient was found with the $PP_{Canavan}$ ($r = 0.86$, $P < 0.001$). The high correlation coefficients between the power measured and estimated can be ambiguous. These relationships only identify that as one variable increases, the other also increases. Nonetheless, large and significant differences between these variables are possible, as in the case of the Lewis equation, with a significant underestimation of 74%, compared to $PP_{platform}$, and a correlation of $r = 0.90$, $P < 0.001$.

The Sayers equation was the one from the literature that gave the closest power values to $PP_{platform}$, with an underestimation of 7%, maybe because it was developed from a more heterogeneous population than the other equations. This percentage was slightly higher than the ones reported by Lara et al. [13] in female populations with different level of physical fitness, and by Sayers et al. [9] in male and female athletes and physical education students. In this work, peak power was sometimes even overestimated. Nonetheless, our underestimation was lower than the values reported by Hertogh and Hue [23] in female volleyball players, and Canavan and Vescovi [5], in college females, with differences of -14% and 21%, respectively.

The Harman equation underestimated $PP_{platform}$ by 19%. This value was higher than the percentage differences found in the studies of Lara et al. [13] with a sample of women, and Sayers et al. [9] with a sample of men and women, between power measured on a force
platform and assessed by the equations. In other respect, this result is similar to that previously reported by Hertogh and Hue [23] in male volleyball players (-19%). The Harman equation underestimated power more than Sayer’s one in spite of having been developed from male subjects, probably because the group of Harman showed less jump performance than our subjects, who gave values closer to those reported by Sayers et al.

The Canavan and Vescovi equation underestimated \( P_{\text{platform}} \) in the subjects of the present study by 28%. Finally, the Lewis equation is the one that gave the largest underestimation, with a 74%. From the results of the present study, it seems that the Sayers equation is the best suited to assess power if direct methods of measuring are not available. On the contrary, the Lewis equation is the one that would lead to the results with the larger underestimations. Our results and the data from the literature are supportive of the hypothesis that the equations will assess with different accuracy depending on the jump performance of the population studied.

From the subjects’ jump height and their body mass we have developed the following regression equation from a sample of 161 male applicants to a faculty of sports sciences:

\[
\text{Power} = (62.5 \times \text{jump height (cm)}) + (50.3 \times \text{body mass (kg)}) - 2184.7
\]

Cross validation with a sample of 53 subjects showed no significant differences between power measured directly on the force platform and assessed by our regression equation. The equation overestimated power only by 99.7±7.1 W (0.3%).

The SEE of 246.5 W was lower than those reported by Sayers et al. [9] (from 379.2 to 561.5 W) in their equations, but slightly higher than that reported by Canavan and Vescovi [5] (120.8 W). This SEE only shows that the variability in the data of the present study is slightly higher than that reported by Canavan and Vescovi. This variability might depend on the
population studied, because the group of Canavan and Vescovi [5] was more homogenous than ours, with a wider range of jump heights and power values.

**CONCLUSIONS**

As a conclusion, despite of the development of different equations to assess the power during jumping in the last years, there has been excessive generalization to different populations, without taking account of their jump performance. This could be one of the reasons for the observed variability in the assessment of the power equations studied. Other factors for the variability might be the use of little sample sizes. The power equation developed in the present study has been developed from a population of male applicants to a faculty of sports sciences, that are likely to have similar jump performance than physical education students. Finally, we believe that it would be very interesting to develop power equations for specific populations to achieve more accurate results when direct methods are not available.
REFERENCES


**Table I: Equations proposed in the literature to assess power indirectly.**

<table>
<thead>
<tr>
<th>Authors</th>
<th>Equations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lewis (7)</strong></td>
<td>( \sqrt{4.9 \cdot 9.8 \cdot \text{body mass (kg)} \cdot \sqrt{\text{jump height (m)}}} )</td>
</tr>
<tr>
<td><strong>Harman (8)</strong></td>
<td>( 61.9 \cdot \text{jump height (cm)} + (36 \cdot \text{body mass (kg)}) - 1822 )</td>
</tr>
<tr>
<td><strong>Johnson and Bahamonde (12)</strong></td>
<td>( 78.5 \cdot \text{jump height (cm)} + (60.6 \cdot \text{body mass (kg)}) - (15.3 \cdot \text{height (cm)}) - 1308 )</td>
</tr>
<tr>
<td><strong>Sayers (21)</strong></td>
<td>( 60.7 \cdot \text{height SJ (cm)} + (45.3 \cdot \text{body mass (kg)}) )</td>
</tr>
<tr>
<td></td>
<td>( 51.9 \cdot \text{height CMJ (cm)} + (48.9 \cdot \text{body mass (kg)}) )</td>
</tr>
<tr>
<td><strong>Shetty (22)</strong></td>
<td>( 1925.72 \cdot \text{jump height (m)} + (14.74 \cdot \text{body mass (kg)}) )</td>
</tr>
<tr>
<td><strong>Canavan and Vescovi (5)</strong></td>
<td>( 65.1 \cdot \text{jump height (cm)} + (25.8 \cdot \text{body mass (kg)}) )</td>
</tr>
</tbody>
</table>

\( SJ = \text{squat jump}; \ CMJ = \text{counter movement jump.} \)
Table II: Jump performance variables analyzed.

<table>
<thead>
<tr>
<th></th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Height</strong> (cm)</td>
<td>34.6 (4.3)</td>
</tr>
<tr>
<td><strong>PF</strong> (BW)</td>
<td>2.43 (0.26)</td>
</tr>
<tr>
<td></td>
<td>(N) 1663.9 (291.1)</td>
</tr>
<tr>
<td><strong>FC</strong> (BW)</td>
<td>2.33 (0.32)</td>
</tr>
<tr>
<td></td>
<td>(N) 1607.0 (297.0)</td>
</tr>
<tr>
<td><strong>PP</strong> (W/kg)</td>
<td>50.05 (5.21)</td>
</tr>
<tr>
<td></td>
<td>(W) 3524.4 (562.0)</td>
</tr>
<tr>
<td><strong>AP</strong> (W/kg)</td>
<td>27.77 (3.30)</td>
</tr>
<tr>
<td></td>
<td>(W) 1956.9 (335.0)</td>
</tr>
</tbody>
</table>

*PF = peak vertical force; BW = body weight; FC = force at the transition from eccentric to concentric phase; PP = peak power; AP = average power.*
Table III: Peak power values measured on the force platform and assessed by the power equations, in the population studied.

<table>
<thead>
<tr>
<th>Platform</th>
<th>Mean (SD)</th>
<th>% diff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lewis</td>
<td>897.9 (120.8)</td>
<td>-74.35</td>
</tr>
<tr>
<td>Harman</td>
<td>2855.9 (407.8)</td>
<td>-18.54</td>
</tr>
<tr>
<td>Sayers</td>
<td>3232.1 (471.0)</td>
<td>-7.87</td>
</tr>
<tr>
<td>Canavan</td>
<td>2533.2 (346.7)</td>
<td>-27.63</td>
</tr>
</tbody>
</table>

All of the values assessed show significant differences ($P < 0.001$) with power measured on the force platform. 
(diff=difference).
Table IV: Correlation matrix between power assessed by the equations and measured on the force platform.

<table>
<thead>
<tr>
<th></th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Platform - Lewis</td>
<td>0.90  ***</td>
</tr>
<tr>
<td>Platform - Harman</td>
<td>0.89  ***</td>
</tr>
<tr>
<td>Platform - Sayers</td>
<td>0.90  ***</td>
</tr>
<tr>
<td>Platform - Canavan</td>
<td>0.86  ***</td>
</tr>
</tbody>
</table>

*** = P < 0.001.
FIGURES

Figure 1: Representative counter movement jump divided into the eccentric and concentric phases, showing the vertical force and power during the push off.