The selection of a method for estimating power output from jump performance

Lara, Amador (1)
Alegre, Luis M. (1)
Abián, Javier (1)
Jiménez, Luis (2)
Ureña, Aurelio (3)
Aguado, Xavier (1)

(1) Facultad de Ciencias del Deporte, Universidad de Castilla-La Mancha. Toledo, Spain.
(2) Escuela Superior de Ingeniería Informática, Universidad de Castilla la Mancha, Ciudad Real, Spain.

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

The purposes of this study were, firstly, to evaluate the power output of leg extensor muscles in a Counter-movement jump test (CMJ) and in a Squat jump test (SJ), in four groups of young women, with different levels of physical activity. Secondly, to obtain power regression equations for the power developed in the CMJ, in the four groups. Forty six young women volunteered for the study. They were divided in 4 groups: 12 elite female volleyball players (Elite); 13 club level female volleyball players (Medium), from a national level team; 10 female physical education students (Students); and 12 sedentary female university students (Sedentary). Peak power values measured on the force platform (Elite: 2997 ± 420 W in CMJ and 3109 ± 420 W in SJ; Medium: 2856 ± 554 W in CMJ and 2879 ± 539 W in SJ; Students: 2415 ± 316 W in CMJ and 2423 ± 277 W in SJ; and Sayers: 2400 ± 395 W in CMJ and 2322 ± 355 W in SJ) were greater than those assessed on with the power equations in most cases. There were significant differences (P<0.001) between power measured and estimated by the equations, in all of them, except for the Sayers equation in the CMJ. This equation was the most accurate, compared to the values measured on the force platform. As jump performance of the subjects increased, the equations underestimated less peak power. Further studies should determine power equations adapted to the characteristics of different groups than those analysed in this study.

Key words: peak power, force platform, jump tests, power equations.
Introduction

Mechanical power is an essential variable for the performance in sport and in the daily activities, and has been studied by researchers for a long time. Jump tests have been frequently utilized to evaluate peak power output from lower limb extensor muscles. These tests can be performed in little space, and have simple and standardize protocols, thus they are widely utilized by researchers and coaches. Nowadays, there are instruments available, like force platforms, that allow to measure power directly, and can be used in the field, doing measurements during a training session or in the rest periods of a competition.

When direct measurements of power are not available, power equations can be utilized, which estimate peak power from jump height and subjects’ body mass (Table 1). Some of these equations have been commonly used by coaches and physical education teachers, but they have been reported to be inaccurate (Harman et al., 1991; Canavan and Vescovi, 2004).

Power is the product of force and velocity \[ P \text{ (W)} = F \text{ (N)} \cdot v \text{ (m/s)} \]. But two different subjects can develop different peak power with the same jump height, from different combinations of force and velocity (Lara et al., 2005). This fact is closely related to the training level and the gender of the population studied. At the extremes of the peak power values, would be an elite male athlete, and at the lower values, a sedentary woman. Thus, the equations generated to assess peak power from a jump should be adapted to each population.
In addition, the equations proposed by Lewis (Fox and Mathews, 1974) and Harman (Harman et al., 1991), underestimate peak power, compared to direct measurements. The degree of this underestimation varies substantially in the literature (Table 2). These differences could have been caused by the different characteristics of the groups studied. With the Lewis equation, peak power values have been underestimated from -70.61% in physically active men to -76.73% in elite male volleyball players (Harman et al., 1991; Hertogh and Hue, 2002). However, the equations proposed later by Sayers (Sayers et al., 1999) assessed better the peak power and even overestimated the power values from 0.83% in sedentary men to 3.26% in athletes and physical education students (Sayers et al., 1999; Hertogh and Hue, 2002). In a recent study, Canavan and Vescovi (2004) have determined a new regression equation (Table 1), from a group of 20 recreationally trained female basketball players (age, 20.1 ± 1.6 years; body mass, 65.9 ± 8.9 kg). Nonetheless, and with the data in Table 2, it is hypothesised that the accuracy of the power equation will change depending on the characteristics of the population studied.

The purposes of this study were, firstly, to evaluate the power output of leg extensor muscles in a Counter-movement jump test (CMJ) and in a Squat jump test (SJ), in four groups of young women, with different levels of physical activity. Secondly, to discuss about the methods of assessing power from the jump tests of each group. And finally, to obtain power regression equations for the power developed in the CMJ, in the four groups.

Methods
Equipment

Typical anthropometric and descriptive measures were obtained from each subject with a weighting scale (SECA Ltd., Germany), an anthropometric rod (SECA Ltd., Germany), an anthropometer (GPM, SiberHegner Ltd., Japan), a plastic tape (Holtain Ltd., United Kingdom), and a spreading calliper (GPM, SiberHegner Ltd., Japan).

A Quattro Jump portable piezoelectric force plate (Kistler, Switzerland) connected to a computer was used to assess jump performance variables by recording force-time measurements at 500 Hz.

Subjects

Forty six young women volunteered for the study. They were divided in 4 groups: 12 female volleyball players, from the Spanish National Team (Elite); 13 club level female volleyball players (Medium), from a national level team; 10 female students from the first course of the sports sciences degree, all of them physically active (Students); and 12 sedentary female university students (Sedentary). Descriptive characteristics of each group are given in Table 3.

Protocols

The subjects performed the jump tests, CMJ and SJ, on the force platform. All of them had been familiarised in a previous day with the feed-back option of Quattro Jump software, which was used to show the subjects force-time graphics in real-time, while they were performing jumps on the force platform. Before the tests, all the subjects carried out a standardised 10 min warm up. The jump tests were performed in the
following order: CMJ, with maximum knee flexion not controlled, and SJ, with a knee angle of 90 degrees and keeping the squatted position for 3 s before the jump. All SJs and CMJs were performed with the hands placed on hips. Each subject was asked to perform 3 to 5 valid trials, and the best performance was recorded. There was a 1-min rest between each trial and 1.5-min between each test condition.

Variables

The variables studied in the jump tests were the height of rise of centre of gravity and peak power developed during the push-off phase, and peak power was also assessed by the Sayers and Canavan equations (Table 1).

Statistical analysis

The data were analysed using the software package Statistica for Windows (v. 5.1, StatSoft, USA). Descriptive statistics include mean and standard deviations (SD). Relationships between power values from each equation were examined using Pearson product moment correlations. Differences between power values were tested with the Mann-Whitney U-test. Multiple regression was used to determine the new power prediction equations. To evaluate the accuracy of one of the power equation developed for the Students group, a cross validation was performed with 11 female physical education students.

Results

The power values measured on the force platform and assessed by the power equations are presented in Table 4. Elite group developed the higher peak power, with values of 2997 ± 470 W in CMJ and 3109 ± 470 W in SJ. It was followed by Medium, Students
and finally, by the Sedentary group, who had power values of 2400 ± 395 W in CMJ and 2322 ± 355 W in SJ. Peak power was greater in the SJ in all the groups, except for the Sedentary group. The Canavan and Sayers equations underestimated power values compared to those measured on the force platform and there were significant differences (P<0.001) in all the measures, except for the Sayers equation in CMJ. The cross validation showed that the proposed equation for female physical education students was more accurate than the previous ones, with a slight underestimation compared to power measured directly (-1.3%, not significant), while in the other equations, there were significant differences compared to power measured directly (-12.7%, P<0.001 and -26.7, P<0.001, with the Sayers and Canavan equations, respectively).

Discussion

With the Sayers equation, similar power values between athletes and physical education students have been reported in the literature (Sayers et al., 1999). Nonetheless, this equation underestimated peak power (-13.98%) in male volleyball players, and overestimated it (0.83%) in sedentary populations, with differences depending on the gender of the population (Hertogh and Hue, 2002) (Table 2). Therefore, the Sayers equation could be more accurate depending on the jump performance of the population studied. Sayers et al. (1999) included a combination of recreational athletes and physical education students, and it would be logical that their equations were more accurate on similar populations, as Shetty (2002) proposed in his paper, where a generalised equation for untrained college-aged subjects was determined by multiple regression. The power values assessed with the Sayers equation were more accurate with the CMJ equation (from -4.33% to -6.87% of underestimation, in the 4 groups studied) than with the SJ equation (from -10.78% to -19.76%). These differences could have occurred by
the technique required to perform a correct SJ, because it is difficult to reach the highest jump height with a proper technique, and this fact could have affected the power values from the equations, with lower values for the SJs.

The Canavan equation underestimated power values more than the Sayers equation in all of the groups in this study, with differences from -23.50% to -41.34%. The explanation would be the different groups utilised by each author to develop their equations. Canavan and Vescovi (2004) used a homogeneous group of 20 women, while Sayers et al. (1999) included 108 subjects (59 men and 49 women).

In populations with greater power output, the Canavan equation decreases its underestimation. This fact supports our previous observation, which pointed out the necessity of using different power equations for different populations. Therefore, we have developed new power equations adapted to the four groups in the present study (Table 5), although it would be very interesting to have greater sample sizes. The cross validation performed on the Students group supports the specificity of the equations to assess power correctly in different populations. Furthermore, the protocols of the CMJ were carefully standardised, with the purpose of having a more homogeneous jump technique among the subjects, decreasing the inter-subject variability during the performance of this test. Using the CMJ as the standard test to evaluate peak power would be more specific than using a SJ, and with standardised protocols, there would be less variability, one of the points that has been criticised by Sayers et al. (1999), in their study.
The power equations showed in Table 5 have been determined from the 4 groups studied, in the CMJ. Estimated power values in similar populations should be very close to those measured directly on a force platform. Likewise, the results of this study point out to the design of different power equations with jump tests different than CMJ, and in groups of different sex, age, and level of physical activity. Thus, coaches and physical education teachers would be able to choose the most suitable equation, depending on the target population.

Conclusions

The Sayers and Canavan equations have underestimated peak power in all the groups studied, except for the Sayers equation in the CMJ test, in the Elite group. This equation was the most accurate, compared to the values measured on the force platform, and seems to be the most suitable to estimate peak power in different groups of young women.

The results of the present study showed that as jump performance of the subjects increased, the equations underestimated less peak power. Further studies should determine power equations adapted to the characteristics of different groups than those analysed in this study.

The equation developed from a group of physical education students was the most accurate for assessing peak power during the push-off phase of a CMJ, compared to the Sayers and Canavan equations. An explanation for these differences would be the use of more standardised protocols in the CMJ performance, compared to the previous studies.
Finally, the conclusions of this study support the use of specific power equations for different populations.

Acknowledgements

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<table>
<thead>
<tr>
<th>Proposed by:</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lewis</strong></td>
<td>( \sqrt[4.9]{9.8 \cdot \text{body mass (kg)} \cdot \sqrt{\text{jump height (m)}}} )</td>
</tr>
<tr>
<td><strong>Harman</strong></td>
<td>((61.9 \cdot \text{jump height (cm)}) + (36 \cdot \text{body mass (kg)}) - 1822)</td>
</tr>
<tr>
<td><strong>Sayers</strong></td>
<td>((60.7 \cdot \text{SJ height (cm)}) + (45.3 \cdot \text{body mass (kg)}) - 2055)</td>
</tr>
<tr>
<td><strong>Canavan</strong></td>
<td>((65.1 \cdot \text{jump height (cm)}) + (25.8 \cdot \text{body mass (kg)}) - 1413.1)</td>
</tr>
</tbody>
</table>
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Table 1
<table>
<thead>
<tr>
<th>Author</th>
<th>N</th>
<th>Gender (M-F)</th>
<th>Age(± SD) (years)</th>
<th>Activity (level)</th>
<th>Tipo de salto</th>
<th>Lewis (± SD) (W)</th>
<th>Power (± SD) (W)</th>
<th>Force platform</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harman et al. (1991)</td>
<td>17</td>
<td>M</td>
<td>28.5 (6.9)</td>
<td>Physically active</td>
<td>JR</td>
<td>1107 (144)</td>
<td>-70.61</td>
<td>3767 (686)</td>
</tr>
<tr>
<td></td>
<td>108</td>
<td>M-F</td>
<td></td>
<td>Athletes and physical education students</td>
<td>CMJ, SJ</td>
<td>1076 (287), 1034 (264)</td>
<td>-72.86, -73.22</td>
<td>3965 (1183), 3861 (1076)</td>
</tr>
<tr>
<td>Sayers et al. (1999)</td>
<td>59</td>
<td>M</td>
<td>21.3 (3.4)</td>
<td>Athletes and physical education students</td>
<td>CMJ, SJ</td>
<td>4624 (877), 4536 (731)</td>
<td>-1.78, -1.82</td>
<td>4708 (889), 4620 (822)</td>
</tr>
<tr>
<td></td>
<td>49</td>
<td>F</td>
<td>20.4 (2.2)</td>
<td>Athletes and physical education students</td>
<td>CMJ, SJ</td>
<td>3169 (567), 3052 (587)</td>
<td>3.26, 1.94</td>
<td>3069 (818), 2994 (543)</td>
</tr>
<tr>
<td>Hertogh and Hue (2002)</td>
<td>9</td>
<td>M</td>
<td>21.2 (3)</td>
<td>Elite volleyball players</td>
<td>CMJ</td>
<td>1246 (78), 4314 (216)</td>
<td>-76.73, -19.44</td>
<td>5355 (522)</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>M</td>
<td>22.2 (3.1)</td>
<td>Sedentary</td>
<td>CMJ</td>
<td>943 (162), 3004 (563)</td>
<td>-72.03, -10.91</td>
<td>3372 (532)</td>
</tr>
</tbody>
</table>
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Table 2
<table>
<thead>
<tr>
<th>Variable</th>
<th>Elite (\bar{X} (\pm SD))</th>
<th>Medium (\bar{X} (\pm SD))</th>
<th>Students (\bar{X} (\pm SD))</th>
<th>Sedentary (\bar{X} (\pm SD))</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>12</td>
<td>13</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>Age (years)</td>
<td>22.0 (4.4)</td>
<td>20.9 (3.3)</td>
<td>18.1 (0.3)</td>
<td>19.9 (1.7)</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>72.49 (6.89)</td>
<td>61.44 (6.17)</td>
<td>58.32 (4.29)</td>
<td>61.69 (12.05)</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.789 (0.066)</td>
<td>1.641 (0.055)</td>
<td>1.634 (0.042)</td>
<td>1.628 (0.069)</td>
</tr>
<tr>
<td>Group</td>
<td>N</td>
<td>Age (± SD) (years)</td>
<td>Test</td>
<td>Power (± SD) (W)</td>
</tr>
<tr>
<td>------------</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sayers % Dif</td>
</tr>
<tr>
<td>Elite</td>
<td>12</td>
<td>22.0 (4.4)</td>
<td>CMJ</td>
<td>3098 (388) 3.37</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>SJ</td>
<td>2774 (382) -10.78</td>
</tr>
<tr>
<td>Medium</td>
<td>13</td>
<td>20.9 (3.3)</td>
<td>CMJ</td>
<td>2703 (450) -5.36</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>SJ</td>
<td>2310 (459) -19.76</td>
</tr>
<tr>
<td>Students</td>
<td>10</td>
<td>18.1 (0.3)</td>
<td>CMJ</td>
<td>2249 (208) -6.87</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>SJ</td>
<td>2066 (195) -14.73</td>
</tr>
<tr>
<td>Sedentary</td>
<td>12</td>
<td>19.9 (1.7)</td>
<td>CMJ</td>
<td>2296 (469) -4.33</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>SJ</td>
<td>1898 (456) -18.26</td>
</tr>
</tbody>
</table>
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Table 4
<table>
<thead>
<tr>
<th>Group</th>
<th>Power CMJ (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Elite</strong></td>
<td>$(83.1 \cdot \text{jump height (cm)}) + (42 \cdot \text{body mass (kg)}) - 2488$</td>
</tr>
<tr>
<td><strong>Medium</strong></td>
<td>$(53.6 \cdot \text{jump height (cm)}) + (67.5 \cdot \text{body mass (kg)}) - 2624.1$</td>
</tr>
<tr>
<td><strong>Students</strong></td>
<td>$(56.7 \cdot \text{jump height (cm)}) + (47.2 \cdot \text{body mass (kg)}) - 1772.6$</td>
</tr>
<tr>
<td><strong>Sedentary</strong></td>
<td>$(68.2 \cdot \text{jump height (cm)}) + (40.8 \cdot \text{body mass (kg)}) - 1731.1$</td>
</tr>
</tbody>
</table>
Legends

Table 1: Power prediction equations in the literature.
(CMJ: Counter-movement jump; SJ: Squat jump)

Table 2: Comparative studies on power output, measured directly and assessed by power equations.
(Dif: difference; JR: jump and reach; CMJ: Counter-movement jump; SJ: Squat jump)

Table 3: Subject characteristics from the four groups
(Elite: female volleyball players, from the Spanish National Team; Medium: female volleyball players from a national level team; Students: physical education students; Sedentary: female university students).

Table 4: Power values measured and assessed, and percentage differences between them in the groups studied.
(Elite: female volleyball players, from the Spanish National Team; Medium: female volleyball players from a national level team; Students: physical education students; Sedentary: female university students; Dif: difference; CMJ: Counter-movement jump; SJ: Squat jump).

Table 5: Proposed regression equations to assess power during a jump, in the groups studied.
(Elite: female volleyball players, from the Spanish National Team; Medium: female volleyball players from a national level team; Students: physical education students; Sedentary: female university students; CMJ: Counter-movement jump).
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