Plyometric muscular action tests in judo- and non-judo athletes

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Abstract. The majority of explosive actions during the Judo fight occur when the athlete is trying to overcome his/her adversary via rapid execution(s) of (isolated or chained) technical manoeuvres. The aim of this study was to compare the results of two plyometric muscular action tests (i.e., Squat Jump – SJ, and Countermovement Jump – CMJ) between judo- and non-judo-athletes.

The investigation involved a cross-sectional examination of 102 subjects (age, 21.9 ± 3.4 years) divided into 3 performance groups: a) Senior top elite judo athletes (n = 50), b) Junior elite judo athletes (n = 26) and c) Adult non-judo athletes (n = 26). Thirteen biomechanical variables (including jump height, velocity, power, force in SJ and CMJ; time to peak force, to peak power and between peaks) were examined. The dataset was analysed using a Univariate analysis of variance.

No significant differences in anthropometric variables were observed between groups. However, significant differences were observed in: a) jump height and peak velocity (SJ, CMJ), b) peak power and peak force (SJ), and c) peak eccentric force, peak eccentric power and peak concentric power (CMJ). We conclude that: a) the center of mass displacement achieved in the CMJ is higher than in the SJ; b) the optimisation of coordination between the eccentric and concentric phases of muscle action is not the primary determinant of performance of Judo athletes; and c) the main pre-requisite for success in elite judo athletes is superior peak eccentric power.

Keywords: Concentric, eccentric, force, judo, plyometric, power, velocity

1. Introduction

Over the last decade, Portuguese Judo athletes have won medals in important international competitions. Both coaches and athletes have become increasingly open to contemporary scientific approaches to the preparation for such events. In fact, modern Judo is characterised by outstanding athletic performance, which itself is based on perfect physical preparation [1, 2]. The majority of explosive actions during the Judo fight occur when the athlete is trying to overcome his/her adversary via the rapid execution of (isolated or chained) technical manoeuvres. Many of the movements that are executed, such as jumping and or throwing, are preceded by a movement in the opposite direction [3]. In the specific case of throwing, a combination of power, speed, as well as synchronized movement of the ankle, knee, and hip, is required. For throwing technique to be effective (i.e. to defeat an opponent), it must be executed both very quickly [4], and with great muscular strength [5]. These actions of high intensity occur at the beginning of contact between the 2 opponents of a fight, and typically only a few seconds elapse between the initiation of the action by the aggressor and the beginning of the projection of the defendee.

Imamura et al. [6] have explained how athletes perform shorter duration Judo throws (of between 300–500 ms), but the literature is equivocal as regards how long is required for complete execution of a throw (e.g., from 0.81 s to 1.22 s [7,8] or 0.65 s [4]).
During competition, efforts are both explosive and powerful. The actions are characterized by quick and sudden changes in limb coordination and rhythm (i.e., a very light manner, during the “drive” or initiation of action; with extreme force, along the projections). This may explain why a short lasting muscular stretch-shorten cycle (SSC) appears to be important to successful bout performance. Several authors have suggested that for the SSC to be effective: a) well-timed pre-activation of the muscle(s) before the onset of the eccentric phase, b) a short and fast eccentric phase, and c) an immediate transition (short delay) between the eccentric and concentric phases of action, are all required.

Moreover, according to the literature both maximal explosive strength and power output of legs seem to be linked to the athlete’s training level and his/her training load [9]. It therefore seems logical that evaluation and control of the strength of judo athletes may allow their coaches to adjust the training process in such a way as to obtain the goal of optimal performance with a minimum of effort. It is clear that the explosive manifestation of force results from the combination of contractile capacity (i.e. understood as the concentric action of the agonist muscles without use of the stretch-shortening cycle [10,11]) and a capacity to synchronize muscle fibre contraction. In accordance, the evaluation of the elastic-explosive phase is usually conducted via the performance of a reactive task- the countermovement jump. The latter exercise assesses the capacity to develop a high force impulse, immediately after a sudden mechanical stretching action [12], or, in other words, a capacity to move quickly from the eccentric to the concentric phase of muscular action.

Thus the objective of this study was to compare the performance of two types of plyometric exercises (SJ and CMJ) of highly trained judo athletes and recreational athletes (non-judo athletes).

2. Method

The experimental protocol was approved by the local University Scientific and Ethical committees. All participants have received detailed explanation regarding the objectives and procedures of the study and signed an informed consent. All of the athletes who participated in the study were highly trained and familiar with the testing procedures in so far as they customarily performed them as part of their normal training/evaluation routine. The data were collected in February, 2009 and, the subjects did not participate in any prolonged exercise within the 24 hour period that preceded the onset of testing.

2.1. Sample

A total of 102 subjects (age, 21.9 ± 3.4 years) took part in the study. The sample was divided into three groups, for comparative purposes: a) Senior top elite judo athletes (n = 50; age, 22.9 ± 2.5 years; stature, 175.78 ± 6.93 cm; body mass, 76.42 ± 11.87 kg), from five National Judo Teams (Portugal, n = 27; Tunisia, n = 10; Brazil, n = 1; France, n = 6; Spain, n = 6), judo specific training volume 8-10 hours/week; b) Junior elite judo athletes (n = 26; age, 18.4 ± 0.9 years; stature, 174.58 ± 6.41 cm; body mass, 74.28 ± 17.70 kg), from the Portuguese National Junior Judo team, undergoing five hours/week of Judo; c) Adult non-judo student athletes (n = 26; age, 23.3 ± 4.0 years; stature, 176.96 ± 6.63 cm; body mass, 72.88 ± 9.75 kg), from the Portuguese Higher Institute of Police Sciences and Internal Security undergoing two hours/week of physical education and two hours/week of Judo. No significant differences between groups were observed in either stature (\(F_{2,99} = 0.817, p = 0.445\)) or body mass (\(F_{2,99} = 0.667, p = 0.516\)).

2.2. Biomechanical profiling

A standardized warm-up lasting ~ 15 min, involving several submaximal contractions of the lower leg muscles (via e.g., squats, leg extension, leg press, and jumps), was carried out before each test session. The participants then performed 3 maximal squat jump (SJ) trials and 3 maximal countermovement jump (CMJ) trials on a Smith machine, whilst standing on a portable force platform (Isonet 500, JLML, Madrid, Spain) [13]. The bar of the Smith machine, had a linear transducer (LPT; Aurki, Fagor Corporation) both attached to it (Isocontrol, JLML, Madrid, Spain) which was synchronized with the force platform. The force platform was connected to a portable computer and recorded data at a sample rate of 1kHz. The rotary encoder of the linear transducer recorded the position and direction of the bar to with an accuracy of 0.0002 m. Peak power was calculated as the product of velocity, as measured by the linear transducer, and ground reaction force, as measured by the portable force platform.

The SJ was initiated from a squatting position, with the knee angle of the subject at 90°. Then, upon an auditory command, each subject vigorously extended
their knees and hips so as to jump vertically up off the ground. They initiated the CMJ from a standing position – first performing a crouching action followed immediately by a jump to maximal height [14]. Subject’s hands held the bar for the entire duration of the movement – such that bar-shoulder contact was always maintained for the duration of each trial. Three minutes of rest were provided between each trial, to maximise inter-trial recovery.

For the purposes of analysis, the CMJ was divided into 2 phases (eccentric and concentric). The eccentric phase comprehends: a) the downward segment, defined as being from the initiation of movement until maximum negative velocity occurred (Fig. 1: Area 1), and b) the transition segment, defined as being from the moment after maximum negative velocity until the end of the eccentric phase when velocity is 0 m/s (Fig. 1: Area 2). The concentric phase comprehends: a) the push off segment, defined as being from the moment after the end of the eccentric phase until maximal positive velocity was achieved (Fig. 1: Area 3), and b) the take-off segment, defined as being from the maximum upward vertical velocity until the instant of take-off (Fig. 1: Area 4).

In total, we assessed 13 separate variables (jump height, velocity, power, force; time to peak force, to peak power and between peaks, for both in SJ and CMJ; as well as jump height) for our athlete sample. Our data collection methodology has been previously validated [15,16]. The accuracy of our calculations, expressed as a coefficient of variation (CV) [17] for each measure, can be viewed in Table 1. All our measurements were obtained by the same, experienced, investigator.

2.3. Statistical analyses

The results were expressed in terms of means and standard deviations (mean ± SD) for all the dependent variables. The dataset was analysed using a one way ANOVA in which the level of performance (senior judo
athletes; junior judo athletes; non-judo athletes) was taken as the between-participant variable. Follow-up multiple comparisons (LSD Post Hoc) test were used where appropriate, to isolate any differences between groups. For all analyses, the level of significance was defined as $p \leq 0.05$. All calculations were performed using the SPSS statistical package (Statistical Package for the Social Sciences Inc, version 17.0, Chicago, Illinois, USA).

3. Results

Significant differences were observed between groups in: a) jump height and peak velocity (SJ: $F_{2.99} = 14.877; F_{2.99} = 7.165$; CMJ: $F_{2.99} = 28.007; F_{2.99} = 11.971$), b) peak power and peak force (SJ: $F_{2.99} = 11.992; F_{2.99} = 4.243$), and c) peak eccentric force, peak eccentric power and peak concentric power (CMJ: $F_{2.99} = 13.679; F_{2.99} = 1.499; F_{2.99} = 22.280$).

The senior judo athletes displayed significantly lower squat jump height, peak velocity and peak power than non-judo athletes (all, $p \leq 0.001$) and, significantly lower squat jump height than the junior judo athletes ($p = 0.044$). Nevertheless, the junior judo athletes performed significantly worse than non-judo athletes on all SJ-related variables (jump height, $p = 0.004$; peak velocity, $p = 0.022$; peak power, $p \leq 0.001$; peak force, $p = 0.005$).

As for the performance of the CMJ, the senior and junior judo athletes displayed significantly lower jump height (both, $p \leq 0.001$) and peak velocity ($p \leq 0.001$; $p = 0.003$) than did the non-judo athletes. However, the senior judo athletes exhibited significantly greater values than non-judo athletes of peak eccentric power ($p = 0.001$), and lower values of peak concentric power ($p \leq 0.001$). The junior judo athletes also performed significantly worse than the non-judo athletes as regards peak concentric power ($p \leq 0.001$). The junior judo athletes also performed significantly worse in relation to peak eccentric force (Judo athletes, $p \leq 0.001$; Non-Judo athletes, $p < 0.01$), but no significant differences were observed between groups in the peak concentric force. No significant differences were found between groups in the time-curves of both tests. Our data values may be viewed in Table 2.

4. Discussion

The majority of explosive actions during the fight occur when the athlete is trying to overthrow his or her adversary via the rapid execution of a technical (isolated or chained) manoeuvre. For this reason, we considered it relevant to compare the results of two phisometric muscular action tests between judo athletes and non-judo athletes.

In accordance with the results of Kyröläinen et al. [18], we observed that the center of mass (c.m.) displacement that was achieved in the CMJ was higher than that achieved within the SJ (for all groups). In fact, during stretching, potential elastic energy is stored in the serial elastic elements [19]. Said energy is only used (in the form of mechanical work) immediately after the concentric work (increasing the creation of force in the subsequent phase) with less metabolic expense and higher mechanical efficiency. With respect to the contractile component, the optimal length for production of a maximum force implies a short stretching of the muscle in relation to the length at rest (i.e. 10–30%). However, Fukashiro et al. [20,21] have suggested that different performances in the SJ and CMJ result (mainly) from the action of the thigh extensor muscles (to the detriment of the effect of elastic potential energy).

It is evident that this kind of movement benefits from the stretch-shortening cycle (SSC). Moreover, previous work has demonstrated that a pre-stretch can enhance the force production and work output of the muscles in a subsequent movement [22]. In other words, the SJ does not involve pre-stretching of muscles. Consequently,
we consider it to be a slightly artificial movement – as well as one that is rarely used in practice. We suggest the CMJ to be a much more natural movement.

Most subjects can jump several centimetres higher in a CMJ than in a SJ. The relation between the CMJ to be a much more natural movement as well as one that is rarely used in practice. We suggest we consider it to be a slightly arti

Table 2
Biomechanical performances (mean ± SD) and comparison of assessed variables between the 3 groups of study participants (N = 102)

<table>
<thead>
<tr>
<th>Judo athletes</th>
<th>Non-Judo athletes</th>
<th>LSD Post Hoc</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Senior (1)</td>
<td>Junior (2)</td>
</tr>
<tr>
<td>Squat Jump (SJ)</td>
<td>50</td>
<td>26</td>
</tr>
<tr>
<td>Jump height (cm)</td>
<td>39.25 ± 5.64</td>
<td>42.73 ± 7.26</td>
</tr>
<tr>
<td>Peak velocity (m/s)</td>
<td>2.95 ± 0.37</td>
<td>3.10 ± 0.58</td>
</tr>
<tr>
<td>Peak power (W/kg)</td>
<td>34.24 ± 7.80</td>
<td>34.40 ± 6.12</td>
</tr>
<tr>
<td>Peak force (N/kg)</td>
<td>14.92 ± 3.34</td>
<td>13.92 ± 2.57</td>
</tr>
<tr>
<td>Countermovement Jump (CMJ)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jump height (cm)</td>
<td>41.20 ± 6.71</td>
<td>44.50 ± 5.86</td>
</tr>
<tr>
<td>Peak velocity (m/s)</td>
<td>3.17 ± 0.38</td>
<td>3.36 ± 0.39</td>
</tr>
<tr>
<td>Peak eccentric force (W/kg)</td>
<td>13.36 ± 5.30</td>
<td>11.79 ± 5.53</td>
</tr>
<tr>
<td>Peak eccentric force (N/kg)</td>
<td>15.31 ± 4.43</td>
<td>9.04 ± 5.96</td>
</tr>
<tr>
<td>Peak concentric force (N/kg)</td>
<td>29.63 ± 6.29</td>
<td>31.58 ± 6.64</td>
</tr>
<tr>
<td>Peak concentric power (W/kg)</td>
<td>15.20 ± 3.22</td>
<td>15.40 ± 2.75</td>
</tr>
<tr>
<td>Time to peak force (ms)</td>
<td>699.40 ± 196.94</td>
<td>707.04 ± 181.07</td>
</tr>
<tr>
<td>Time to peak power (ms)</td>
<td>858.92 ± 161.85</td>
<td>888.12 ± 158.43</td>
</tr>
<tr>
<td>Time between peaks (force and power) (ms)</td>
<td>195.80 ± 123.90</td>
<td>185.92 ± 104.43</td>
</tr>
</tbody>
</table>

Significant difference between groups: *p < 0.05; **p < 0.01; ***p < 0.001.

According to current literature [24,25], elevated force levels during the eccentric phase will allow individuals to achieve higher acceleration rates at the beginning of (and throughout) the concentric phase of jump. Consequently, they will perform at a greater vertical velocity at take-off (which will then translate into improved displacement).

It is clear that senior judo athlete express superior values in the impulse due to the ground force reaction. However, our results suggest that these athletes cannot make the most of their aforesaid superiority (i.e. greater eccentric force in the implied muscles).

It is also evident that in Judo, the rapid transition from the eccentric to concentric phase occurs especially in explosive actions, such as the throwing techniques [26]. This moment between the eccentric and the concentric phase is called the “damping phase”. It follows that the damping phase can be perfected (i.e. shortened, leading to an increase in velocity [27]) via the execution of plyometric work. In other words, plyometric training allows the muscle to make a rapid transition between the eccentric and concentric phases of the muscular action [27], generating a more accentuated force than would have been possible without the optimisation of the eccentric phase [28].

Some authors consider the “potentiation” effect [29] to be more important than the effective use of the elastic accumulated energy. However, whether the potential
5. Conclusions

This study provides a specific plyometric profile of the judo athlete and non-judo athletes. It is suggested that: a) the center of mass displacement achieved in the CMJ is higher than in the SJ; b) the optimisation of coordination between the eccentric and concentric phase of action is probably not the main pre-requisite for performance in judo athletes; and c) the main pre-requisite for success in elite judo athletes is a superior peak eccentric power.

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References


