EFFECT OF SQUAT DEPTH ON MAXIMUM HEIGHT VERTICAL JUMPING

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INTRODUCTION

Maximum vertical jumping has received considerable biomechanical attention (e.g. Alexander, 1990; Challis, 1998; van Soest et al., 1985), and much is known about optimal performance (Pandy and Zajac, 1991). Jump height is a function of the vertical impulse generated during the ground contact phase of the jump. If somebody wants to jump higher, greater impulse can be generated by applying greater forces, or applying forces for a longer period. One option for increasing the duration of force application is to jump from a deep squat position. There are no studies which have explicitly examined the influence initial squat depth on jump height.

Bobbert et al. (1996) asked subjects to perform squat jumps from a preferred position, a position matching the bottom of jumps performed with a countermovement, and from a deep squat position. They found no difference in jump height between these conditions, suggesting that increased squat depth does not increase jump height but nor does it decrease jump height. They performed not further comparisons between these conditions. Selbie and Caldwell (1996) used a simple simulation model to investigate the effect of initial position on countermovement jump height. Initial position had only small effects on jump height, but these were countermovement jumps and the bottom most position in the jumps was very similar for all jumps irrespective of initial position. Van Soest et al. (1994) used a direct dynamics simulation to investigate how muscle model activation patterns influence jumps made from different initial positions. They found that a common activation pattern for different initial positions produced similar jump heights all close to the optimal jump height. Their study suggests that jumping from a deeper initial squat might not require significant changes in muscle activation patterns.

A number of studies have indicated that jump height may not be significantly influenced by initial squat positions, but none of these studies systematically examined the influence of squat depth on jump height. It is the purpose of this study to examine the effect of squat depth on maximum vertical jump performance.

METHODS

Ten healthy male subjects (age: 23.9 ± 2.72 years; height: 183.3 ± 6.19 cm; body mass: 85.5 ± 17.4 kg) participated in the study. All subjects provided informed consent; all procedures were approved by the institutional review board. Subjects performed nine maximum vertical jumps commencing from an initial squat position. Three were performed from the preferred starting position. The subjects were then asked to perform three jumps from a self-selected deeper squat and three jumps from a more upright posture. During all the jumps the subjects kept their hands on their hips, to eliminate arm motion. Subjects warmed-up prior to testing, and rested for at least one minute between jumps.

Kinematic data were obtained using a Pro-Reflex Motion Analysis System (Qualisys, Inc.), sampling at 240 Hz. Markers were placed on the following body landmarks: acromion process, great trochanter, lateral femoral condyle, lateral maleolus, and the base of the fifth metatarsal. Ground reaction force data were synchronously sampled with the motion analysis data using a force platform (N50601, Bertec Corporation, Worthington, Ohio) sampling at 1200 Hz.

Jump height was assumed to be the maximum vertical displacement of the center of mass once contact was lost with the ground. It was computed from the center of mass vertical take-off velocity, which was determined from the impulse obtained by integrating the vertical ground reaction force-time curve with respect to time. Jump time is the time from movement initiation to takeoff.

Resultant joint moments in the sagittal plane were computed for the ankle, knee, and hip joints (Winter, 1990). To determine these moments the segmental inertial parameters were determined for each subject by modeling their segments as series of geometric solids (Yeadon, 1990). The densities of these segments were derived from the cadaver data of Clauser et al. (1969). Joint moments were normalized by dividing by body mass.

Figure 1 shows the angle convention used for the study. All joints are at zero degrees in a standing posture. Extension velocities and moments are negative. Flexion velocities and moments are positive.

From the time histories of the joint angles, angular velocities, and resultant moments the maximum joint velocities and the maximum and minimum joint moments were measured. The timing of these events was also measured and expressed as time before takeoff. To evaluate the statistical differences a two-way repeat measures analysis of variance (ANOVA) was used. The initial joint
angles and center of mass height were compared to ensure subjects self selected positions were different from the preferred position. Post-hoc comparisons, where appropriate, were made using a Tukey test. For all statistical comparisons a significance level of 0.05 was used. Homogeneity of variance was confirmed for the data prior to performing the ANOVA using a Bartlett test.

RESULTS AND DISCUSSION

There was a statistical difference between initial positions of the center of mass in the three conditions. There was statistically increased flexion at the knee and hip as the depth of squat increased. Ankle flexion increased from the upright posture to the preferred posture, however there was no statistical difference between the preferred initial ankle position and the deep initial ankle position (Table 1).

There was a statistically significant increase in jump time as squat depth increased (Table 2). Jumps performed from the most upright posture were significantly lower than jumps performed from deeper postures, however there was no statistical difference between jump heights at the preferred or deep postures (Table 2).

There were no differences in maximum (Table 3) or minimum (table 4) joint moments between jump heights at the preferred or deep postures, however the timing of the Minimum joint moments at the knee and ankle occurred earlier in the jumps from the deep squat. The patterns of joints moments were less smooth in the jumps from the deep position. Figure 2 shows a typical pattern of knee moments for jumps performed from the deep and preferred posture.

Table 1: Means and standard deviations of the initial squat positions in the jumps for each of the conditions.

<table>
<thead>
<tr>
<th></th>
<th>Deep Squat</th>
<th>Preferred</th>
<th>Upright</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center of mass height</td>
<td>0.56 ± 0.07 m</td>
<td>0.68 ± 0.07 m</td>
<td>0.79 ± 0.06 m</td>
</tr>
<tr>
<td>Hip angle</td>
<td>105.5 ± 17.2°</td>
<td>77.4 ± 15.5°</td>
<td>45.4 ± 13.8°</td>
</tr>
<tr>
<td>Knee angle</td>
<td>99.8 ± 16.0°</td>
<td>79.7 ± 10.3°</td>
<td>56.2 ± 10.9°</td>
</tr>
<tr>
<td>Ankle angle</td>
<td>7.49 ± 7.16°</td>
<td>6.46 ± 8.02°</td>
<td>0.05 ± 7.10°</td>
</tr>
</tbody>
</table>

Note – + - indicates that statistically significant difference exists preferred and deep squat conditions. * - indicates that statistically significant difference exists preferred and upright squat conditions. @ - indicates that statistically significant difference exists upright and deep squat conditions.

Table 2: Mean and standard deviations of jump heights and jump times for each of the conditions.

<table>
<thead>
<tr>
<th></th>
<th>Deep Squat</th>
<th>Preferred</th>
<th>Upright</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jump time</td>
<td>0.67 ± 0.14 s</td>
<td>0.59 ± 0.10 s</td>
<td>0.52 ± 0.12 s</td>
</tr>
<tr>
<td>Jump height</td>
<td>0.27 ± 0.06 m</td>
<td>0.27 ± 0.06 m</td>
<td>0.21 ± 0.06 m</td>
</tr>
</tbody>
</table>

Note – + - indicates that statistically significant difference exists preferred and deep squat conditions. * - indicates that statistically significant difference exists preferred and upright squat conditions. @ - indicates that statistically significant difference exists upright and deep squat conditions.

Table 3: Normalized minimum joint moments and times for each of the conditions.

<table>
<thead>
<tr>
<th></th>
<th>Deep Squat</th>
<th>Preferred</th>
<th>Upright</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip moment</td>
<td>-0.94 ± 0.20 Nm/kg</td>
<td>-1.04 ± 0.17 Nm/kg</td>
<td>-1.00 ± 0.14 Nm/kg</td>
</tr>
<tr>
<td>Time of min hip moment</td>
<td>0.13 ± 0.15 s</td>
<td>0.11 ± 0.14 s</td>
<td>0.14 ± 0.14 s</td>
</tr>
<tr>
<td>Knee moment</td>
<td>-0.62 ± 0.12 Nm/kg</td>
<td>-0.61 ± 0.15 Nm/kg</td>
<td>-0.51 ± 0.09 Nm/kg</td>
</tr>
<tr>
<td>Time of min knee moment</td>
<td>0.31 ± 0.11 s</td>
<td>0.26 ± 0.05 s</td>
<td>0.25 ± 0.07 s</td>
</tr>
<tr>
<td>Ankle moment</td>
<td>-0.57 ± 0.11 Nm/kg</td>
<td>-0.57 ± 0.14 Nm/kg</td>
<td>-0.50 ± 0.08 Nm/kg</td>
</tr>
<tr>
<td>Time of min ankle moment</td>
<td>0.31 ± 0.08 s</td>
<td>0.25 ± 0.08 s</td>
<td>0.23 ± 0.09 s</td>
</tr>
</tbody>
</table>

Note – + - indicates that statistically significant difference exists preferred and deep squat conditions. * - indicates that statistically significant difference exists preferred and upright squat conditions. @ - indicates that statistically significant difference exists upright and deep squat conditions.

SUMMARY

Increasing the depth of squat beyond the preferred position had no effect on jump height despite additional time to develop force. The early onset of maximum joint moments slowing joint extensions in jumps from a deep squat could suggest that the subjects do not coordinate these jumps optimally. As the subjects presumably do not normally jump from these greater depths, it is feasible that with training the subjects may jump higher from this position than they do from their preferred depth. A simulation study could be performed to test this. If the neural input is determined by an optimal controller then the simulation is equally well coordinated jumping from any initial position. The simulation is therefore likely to jump higher from a deep squat position.
Table 4. Normalized maximum joint moments and times for each of the conditions. (Times are expressed as time before takeoff. Flexion moments are positive.)

<table>
<thead>
<tr>
<th>Joint</th>
<th>Deep Squat</th>
<th>Preferred</th>
<th>Upright</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip moment</td>
<td>$1.20 \pm 0.53$ Nm/kg</td>
<td>$1.52 \pm 1.06$ Nm/kg</td>
<td>$0.79 \pm 0.23$ Nm/kg</td>
</tr>
<tr>
<td>Time of max hip moment</td>
<td>$0.10 \pm 0.10$ s</td>
<td>$0.12 \pm 0.16$ s</td>
<td>$0.10 \pm 0.05$ s</td>
</tr>
<tr>
<td>Knee moment</td>
<td>$0.78 \pm 0.15$ Nm/kg</td>
<td>$0.86 \pm 0.11$ Nm/kg</td>
<td>$0.84 \pm 0.13$ Nm/kg</td>
</tr>
<tr>
<td>Time of max knee moment</td>
<td>$0.09 \pm 0.10$ s</td>
<td>$0.09 \pm 0.11$ s</td>
<td>$0.10 \pm 0.05$ s</td>
</tr>
<tr>
<td>Ankle moment</td>
<td>$0.83 \pm 0.14$ Nm/kg</td>
<td>$0.91 \pm 0.10$ Nm/kg</td>
<td>$0.89 \pm 0.13$ Nm/kg</td>
</tr>
<tr>
<td>Time of max ankle moment</td>
<td>$0.13 \pm 0.15$ s</td>
<td>$0.14 \pm 0.19$ s</td>
<td>$0.10 \pm 0.05$ s</td>
</tr>
</tbody>
</table>

Note – + - indicates that statistically significant difference exists preferred and deep squat conditions. * - indicates that statistically significant difference exists preferred and upright squat conditions. @ - indicates that statistically significant difference exists upright and deep squat conditions.

Figure 2: Knee moments at the preferred and deep squat positions. (Joint extension moments are negative.)

REFERENCES


ACKNOWLEDGEMENTS

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