Relative Net Vertical Impulse Determines Jumping Performance

Tyler J. Kirby, Jeffrey M. McBride, Tracie L. Haines, and Andrea M. Dayne

The purpose of this investigation was to determine the relationship between relative net vertical impulse and jump height in a countermovement jump and static jump performed to varying squat depths. Ten college-aged males with 2 years of jumping experience participated in this investigation (age: 23.3 ± 1.5 years; height: 176.7 ± 4.5 cm; body mass: 84.4 ± 10.1 kg). Subjects performed a series of static jumps and countermovement jumps in a randomized fashion to a depth of 0.15, 0.30, 0.45, 0.60, and 0.75 m and a self-selected depth (static jump depth = 0.38 ± 0.08 m, countermovement jump depth = 0.49 ± 0.06 m). During the concentric phase of each jump, peak force, peak velocity, peak power, jump height, and net vertical impulse were recorded and analyzed. Net vertical impulse was divided by body mass to produce relative net vertical impulse. Increasing squat depth corresponded to a decrease in peak force and an increase in jump height and relative net vertical impulse for both static jump and countermovement jump. Across all depths, relative net vertical impulse was statistically significantly correlated to jump height in the static jump (r = .9337, p < .0001, power = 1.000) and countermovement jump (r = .925, p < .0001, power = 1.000). Across all depths, peak force was negatively correlated to jump height in the static jump (r = –0.3947, p = .0018, power = 0.8831) and countermovement jump (r = –0.4080, p = .0012, power = 0.9050). These results indicate that relative net vertical impulse can be used to assess vertical jump performance, regardless of initial squat depth, and that peak force may not be the best measure to assess vertical jump performance.

Keywords: static, countermovement, power, force

Many investigations have examined the possible relationships among force, power, and jumping ability (Cormie et al., 2009; Dowling & Vamos, 1993; Nuzzo et al., 2008; Peterson et al., 2006; Rousanoglou et al., 2008; Yamauchi & Ishii, 2007). Impulse is a kinetic variable and may be better able to predict performance in jumping. Newton’s second law in momentum form is \( F_{\text{mean}} \Delta t = mv - mv_0 \), where \( F_{\text{mean}} \) is mean force, \( \Delta t \) is the time interval, \( m \) is mass, and \( v \) is the initial \( (v_0) \) and final \( \) velocity. This equation is often referred to as the impulse-momentum theorem, with impulse being represented by \( F_{\text{mean}} \Delta t \) and momentum as \( mv - mv_0 \). During a vertical jump, each of the variables can be expressed in the vertical direction, as those components will contribute to the vertical displacement of the center of mass of the body. Before initiation of the concentric component of the vertical jump, initial velocity \( (v_0) \) is 0 m/s for both the static jump and the countermovement jump. The equation \( F_{\text{mean}} \Delta t = mv - mv_0 \) can be used to determine the velocity of the center of mass of the body at takeoff \( (v) \) by expressing the impulse relative to the body mass: \( (F_{\text{mean}} \Delta t)/m = v - v_0 \), essentially solving for \( v \) (the velocity of the center of mass of the body at takeoff) given that \( v_0 \) is 0 m/s. Using the value of \( v \), calculated above, the kinematic equation \( v_{\text{apex}}^2 = v^2 + 2ax \), allows for the calculation of \( x \) (the displacement of the center of mass of the body or jump height) given that \( v_{\text{apex}} \) is the velocity of the center of mass of the body at the apex \( (0 \text{ m/s}) \) and a constant acceleration value \( (a) \) of –9.81 m/s².

Previous investigations have demonstrated a strong relationship between impulse and sprinting times. Sleinert and Taingahue (2004) found that 5-m sprint times were negatively correlated \( (r = –0.64, p < .05) \) to relative net vertical impulse during the first ground contact. Similarly, Hunter et al. (2005) reported significant \( (p < .001) \) correlations between relative net vertical impulse and sprint velocity \( (r = .755) \), as well as relative net horizontal impulse and sprint velocity \( (r = .781) \). These results demonstrate the necessity for maximal relative net vertical or horizontal impulse to be produced during activities requiring rapid changes in displacement.

Athletes proficient at jumping demonstrate significantly higher values in variables such as force and power in comparison with nonjumpers (Cormie et al., 2009). Several studies have examined how force and power relate to vertical jump height. One investigation found peak force and peak power were both positively related to vertical jump, with peak power being the single best
predictor of jump height (Dowling & Vamos, 1993). Peak power has shown a positive correlation with vertical jump performance in other investigations as well (Nuzzo et al., 2008; Peterson et al., 2006; Rousanoglou et al., 2008; Yamauchi & Ishii, 2007). Although, other studies have reported that peak force contributes minimally to vertical jump performance (Nuzzo et al., 2008; Sheppard et al., 2008). The majority of investigations that examined the influence of peak force and peak power variables on jump height allowed the subjects to self-select their squat depth before initiating the jump. This creates variability between jump trials, which increases the difficulty of identifying relationships between variables and jump height.

To date, few investigations have examined the influence of squat depth on vertical jump height. Domire and Challis (2007) used both an experimental and a modeling approach to determine the effect of squat depth on jump height. In the experimental protocol, participants performed maximal static jumps from a preferred squat depth and a self-selected squat depth that was deeper than their preferred squat depth. It was determined that squat depth had no influence on jump height. From the experimental protocol, a modeling approach was created to simulate jumps from various starting positions. Results from the simulated jumps found that the maximal jump height was attained from the deepest squat depth tested. In a similar investigation, Bobbert et al. (2008) examined the influence of depth on kinetic and kinematic variables during a static jump by utilizing five different squat depths, including a preferred depth, two depths above and two depths below that depth. Squat depth was shown to influence performance variables and jump height (Bobbert et al., 2008). However, neither investigation examined how the variation in squat depth affected relative net vertical impulse and how it related to the differences in jump height.

Therefore, the purpose of the current investigation was to determine the effect of squat depth on relative net vertical impulse and jump height in a countermovement and static jump. In addition, the effect of squat depth on peak force, peak power, and jump height was examined as well.

Methods

Subjects

Ten college-aged males (age: 23.3 ± 1.5 years; height: 176.7 ± 4.5 cm; body mass: 84.4 ± 10.1 kg) participated in this investigation. All subjects were recreationally weight trained with at least 2 years of jumping experience. This included participating in activities requiring proficiency at performing vertical jumps (e.g., competitive basketball, volleyball). The participants were notified about the potential risks involved and gave their written informed consent, approved by the institutional review board at Appalachian State University.

Study Design

Subjects reported to the laboratory for a single testing session. Upon arrival, anthropometric measurements (height, weight) were collected. A 5-min warm-up on a cycle ergometer was performed before any vertical jump testing procedures. Subjects then performed a series of static jumps and countermovement jumps to a depth of 0.15, 0.30, 0.45, 0.60, and 0.75 m and a self-selected depth (static jump depth = 0.38 ± 0.08 m, countermovement jump depth = 0.49 ± 0.06 m). The varying depths from 0.15 to 0.75 m corresponded to knee angles of 121.7 ± 8.1, 104.6 ± 9.0, 93.3 ± 7.6, 76.2 ± 12.4, and 53.2 ± 11.4 degrees respectively. Squat depths were determined from initial displacement values while the subject was standing completely upright and were therefore independent of height differences between subjects. The order in which the jumps were performed was randomly assigned for both the type of jumps (static jump, countermovement jump) and squat depth (preferred depth, 0.15 m, 0.30 m, 0.45 m, 0.60 m, 0.75 m). Subjects held a weightless bar across their upper back ensuring the bar did not move independently of the body, as well as to restrict any arm movement. To determine each squat depth before testing, subjects performed the eccentric portion of the jump in a slow and controlled manner until the desired squat depth was achieved as monitored by instantaneous displacement values displayed on the computer. The mechanism for determining displacement is described below. Subjects were then instructed to maintain that squat depth until knee angle measurements and the squat depth feedback mechanism could be set. The feedback mechanism consisted of a light elastic band (Jump Stretch Inc., Youngstown, OH) positioned under the subjects’ hips at each squat depth, which allowed the subjects to monitor their squat depth before initiating the concentric phase of the countermovement jump. During jump trials, subjects were instructed to perform the eccentric phase of the squat depth as quickly as possible while still reaching the desired squat depth. Subjects were instructed to keep downward pressure on the barbell throughout the entire jump and were encouraged to reach a maximal jump height with every trial. Subjects performed a minimum of five trials at each squat depth for both static jump and countermovement jump, with additional trials being performed if their squat depth differed significantly from the required squat depth (±0.05 m). Adequate rest of 2 min was given between the different squat depth trials.

Data Collection Procedures

All testing was performed with the subject standing on a force plate (BP6001200, AMTI, Watertown, MA) while holding a weightless (plastic) bar across their shoulders. The right side of the barbell was attached to two linear position transducers (LPTs; PT5A-150, Celasco Transducer Products, Chatsworth, CA). The weightless bar acted to counterweight the pull of the two linear position transducers resulting in zero load. The linear position transducers
Relative Net Vertical Impulse

were located above-anterior and above-posterior to the subject and, when attached to the bar, resulted in the formation of a triangle. This allowed for the calculation of vertical and horizontal displacements through trigonometry involving constants and displacement measurements. This method of collecting kinematic variables has previously been validated in our laboratory (Cormie et al., 2007). The combined retraction tension of the linear position transducers was 16.4 N; this was accounted for in all calculations. Analog signals from the force plate and LPTs were collected for every trial at 1000 Hz using a BNC-2010 interface box with an analog-to-digital card (NI PCI-6014, National Instruments, Austin, TX). Custom programs designed using Labview (Version 8.2, National Instruments) were used for recording and analyzing the data.

Data Analysis Procedures

Signals from the two linear position transducers and the force plate underwent rectangular smoothing with a moving average half-width of 12. Displacement-time, force-time, velocity-time, and power-time curves were calculated for each jump. Peak force, peak velocity, peak power, and jump height (jump height) were measured during the concentric phase of the vertical jump for each trial (static jump and countermovement jump). Peak force and peak power values were analyzed with acceleration due to gravity on the subjects’ body mass removed. Peak force was measured as the maximum force reached during the concentric phase. Peak velocity was measured as the change in displacement over time. Peak power was determined as the force multiplied by the velocity. Jump height was determined as the difference between maximum displacement reached during the jump and initial displacement while in a standing position. Net vertical impulse was determined during the propulsive phase for both the static jump and countermovement jump. Propulsive phase was determined as the point when displacement values reached a maximum depth during the bottom of the coupling phase until the force-time curve returned to zero. Net vertical impulse was calculated by removing the vertical impulse exerted through acceleration due to gravity (Figure 1). Net vertical impulse was then divided by the subjects’ body mass to determine relative net vertical impulse. This method for determining relative net vertical impulse was previously used by Hunter et al. (2005).

Statistical Analyses

Independent t tests were used to determine differences between relative vertical impulse and performance variables for each squat depth. Pearson’s product correlations were used to determine if any relationships existed. The significance level was set at $p \leq .05$ for all statistical analyses. All statistical analyses were completed using a statistical software package (SPSS Version 16.0, SPSS Inc., Chicago, IL).

![Figure 1](image)

**Figure 1** — An example of a force-time curve showing how relative vertical impulse and peak vertical force were analyzed.
Results

In both the static jump and countermovement jump, relative net vertical impulse increased with increasing squat depth. Static jump relative net vertical impulse was significantly different between squat depths 0.15 m, 0.30 m, and 0.75 m and all other squat depths ($p \leq .05$) (Table 1). Countermovement jump relative net vertical impulse during the propulsive phase was significantly lower at 0.15 m than all other squat depths. Relative net vertical impulse was significantly higher for the self-selected depth and 0.75 m than all other squat depths (Table 2). Correlations between jump height and relative net vertical impulse were statistically significant for static jump ($r = .9337, p < .0001, power = 1.0000$) and countermovement jump ($r = .9215, p < .0001, power = 1.0000$) (Figure 2).

As squat depth increased, peak force decreased in a linear trend for both the static jump and countermovement jump (Tables 1 and 2). Peak force was significantly different between each squat depth for both static jump and countermovement jump ($p \leq .05$). Static jump peak force for the self-selected squat depth was significantly different from all other squat depths, except the 0.30-m squat depth. Countermovement jump peak force for the self-selected squat depth was significantly different from that of all other squat depths, except the 0.45-m squat depth ($p \leq .05$). Correlations between peak force and jump height were significant for static jump ($r = -0.3947, p = .0018, power = 0.8831$) and countermovement jump ($r = -0.4080, p = .0012, power = 0.9050$) (Figure 3).

Peak power was significantly affected by squat depth in both the static jump and countermovement jump. Static jump peak power was significantly higher at 0.30 m and self-selected depth compared with 0.15 m, 0.45 m, 0.60 m, and 0.75 m ($p \leq .05$) (Table 1). Countermovement jump peak power at 0.30 m was significantly higher than self-selected depth, 0.45 m, 0.60 m, and 0.75 m. Countermovement jump peak power at 0.15 m was higher than 0.60 m and 0.75 m. Countermovement jump peak power

![Figure 2](image)

**Figure 2** — Pearson product correlations between relative vertical impulse and jump height for static jump and countermovement jump. Significant correlations were obtained for both static jump and countermovement jump ($p < .0001$).

Table 1  Comparisons of relative net vertical impulse, peak force, peak power, peak velocity, and jump height for static jump across various squat depths

<table>
<thead>
<tr>
<th>Squat Depth</th>
<th>Relative Net Vertical Impulse (m/s)</th>
<th>Peak Force (N)</th>
<th>Peak Power (W)</th>
<th>Peak Velocity (m/s)</th>
<th>Jump Height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.15 m</td>
<td>1.89 ± 0.30$^a$</td>
<td>1861.38 ± 301.69$^a$</td>
<td>2942.95 ± 953.88</td>
<td>2.78 ± 0.28$^d$</td>
<td>0.27 ± 0.06$^a$</td>
</tr>
<tr>
<td>0.30 m</td>
<td>2.42 ± 0.25$^a$</td>
<td>1472.60 ± 235.93$^b$</td>
<td>3556.28 ± 831.51</td>
<td>2.94 ± 0.22$^f$</td>
<td>0.38 ± 0.07$^a$</td>
</tr>
<tr>
<td>0.45 m</td>
<td>2.58 ± 0.22</td>
<td>1168.02 ± 177.83$^a$</td>
<td>3116.83 ± 704.92</td>
<td>3.13 ± 0.17$^b$</td>
<td>0.44 ± 0.06</td>
</tr>
<tr>
<td>0.60 m</td>
<td>2.61 ± 0.19</td>
<td>987.02 ± 146.72$^a$</td>
<td>2987.42 ± 605.95</td>
<td>3.33 ± 0.24$^c$</td>
<td>0.48 ± 0.07$^b$</td>
</tr>
<tr>
<td>0.75 m</td>
<td>2.74 ± 0.21$^a$</td>
<td>901.98 ± 171.83$^a$</td>
<td>2942.75 ± 740.15</td>
<td>3.37 ± 0.24$^c$</td>
<td>0.48 ± 0.07$^b$</td>
</tr>
<tr>
<td>Self-Selected</td>
<td>2.58 ± 0.18</td>
<td>1425.26 ± 400.01</td>
<td>3739.88 ± 1032.36</td>
<td>3.15 ± 0.22</td>
<td>0.44 ± 0.05</td>
</tr>
</tbody>
</table>

*Note.* Values are expressed as mean ± SD.

$^a$Significant difference from all other squat depths.

$^b$Significant difference from all squat depths except self-selected.

$^c$Significant difference from 0.15 m, 0.45 m, 0.60 m, and 0.75 m.

$^d$Significant difference from all squat depths except 0.30 m.

$^e$Significant difference from all squat depths except each other.

$^f$Significant difference from all squat depths except 0.15 m.

$^g$Significant difference from 0.15-m, 0.30-m, 0.45-m and self-selected squat depths.

$^h$Significant difference from 0.15-m, 0.30-m, and 0.45-m squat depths.
Table 2  Comparisons of relative net vertical impulse, peak force, peak power, peak velocity, and jump height for countermovement jump across various squat depths

<table>
<thead>
<tr>
<th>Squat Depth</th>
<th>Relative Net Vertical Impulse (m/s)</th>
<th>Peak Force (N)</th>
<th>Peak Power (W)</th>
<th>Peak Velocity (m/s)</th>
<th>Jump Height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.15 m</td>
<td>2.38 ± 0.32&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2291.87 ± 535.71&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3909.72 ± 1438.08</td>
<td>2.98 ± 0.42&lt;sup&gt;f&lt;/sup&gt;</td>
<td>0.31 ± 0.07&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>0.30 m</td>
<td>3.06 ± 0.27&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1600.53 ± 308.12&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4137.35 ± 1119.58</td>
<td>3.18 ± 0.24&lt;sup&gt;f&lt;/sup&gt;</td>
<td>0.45 ± 0.06&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>0.45 m</td>
<td>3.10 ± 0.19&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1211.19 ± 235.61&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3508.86 ± 888.88</td>
<td>3.29 ± 0.18&lt;sup&gt;f&lt;/sup&gt;</td>
<td>0.48 ± 0.05&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>0.60 m</td>
<td>3.13 ± 0.22&lt;sup&gt;b&lt;/sup&gt;</td>
<td>972.48 ± 160.75&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3085.96 ± 693.86&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.47 ± 0.28&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.51 ± 0.08</td>
</tr>
<tr>
<td>0.75 m</td>
<td>3.36 ± 0.16&lt;sup&gt;c&lt;/sup&gt;</td>
<td>837.80 ± 138.72&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2864.53 ± 616.55&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.56 ± 0.23&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.53 ± 0.07</td>
</tr>
<tr>
<td>Self-Selected</td>
<td>3.29 ± 0.22&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1245.70 ± 333.72&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3656.37 ± 873.01&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.49 ± 0.15&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.53 ± 0.05</td>
</tr>
</tbody>
</table>

Note. Values are expressed as mean ± SD.
<sup>a</sup>Significant difference from all other squat depths.
<sup>b</sup>Significant difference from all squat depths except self-selected.
<sup>c</sup>Significant difference from 0.15-m, 0.75-m, and self-selected squat depths.
<sup>d</sup>Significant difference from all squat depths except 0.75 m.
<sup>e</sup>Significant difference from 0.45-m, 0.60-m, and 0.75-m squat depths.
<sup>f</sup>Significant difference from all squat depth except 0.30 m.
<sup>g</sup>Significant difference from all squat depth except 0.60-m, 0.75-m, and self-selected squat depths.
<sup>h</sup>Significant difference from 0.15-m, 0.30-m, and 0.45-m squat depths.

Figure 3 — Pearson product correlations between peak vertical force and jump height for static jump and countermovement jump. Significant correlations were obtained for both static jump and countermovement jump (p ≤ .05).

Power at self-selected depth was significantly different than 0.30 m, 0.60 m, and 0.75 m. Countermovement jump peak power at 0.60 m and 0.75 m was significantly lower than all other depths (Table 2). Force-velocity curves for static jump and countermovement jump at each depth are shown in Figures 4 and 5, respectively. These figures are representative of the peak force and peak velocity achieved during the concentric phase of the vertical jump across each squat depth. Peak force and peak velocity for the self-selected squat depth are highlighted.

Figure 4 — Peak vertical force and the peak vertical velocity for each squat depth during static jump trials (preferred depth = 0.38 ± 0.08 m).

Jump height increased with increasing squat depth for both the static jump (Table 1) and countermovement jump (Table 2). Static jump heights at starting depths of 0.15 m, 0.30 m, and 0.45 m were significantly different from all other squat depths (p ≤ .05) (Table 1). Countermovement jump heights at starting depths of 0.15 m, 0.30 m, and 0.45 m were significantly different from all other squat depths. Static jump heights from the self-selected depth were significantly higher than 0.15 m and 0.30 m.
in an isometric leg extensor action has been shown to remain inconsistent within the literature. Peak force may provide the most accurate way of explaining differences in jump performance across a group of individuals. Relative net vertical impulse during the propulsive phase of the vertical jump is not correlated to jump height performance (Nuzzo et al., 2008). Results from this investigation further illustrate that peak force is not a reliable predictor of jump height. While peak force did show a significant correlation with jump height in the current investigation, the correlation was negative with higher jump heights having lower peak force values. The manipulation of squat depth may explain the difference between the correlations found is this investigation and those found by Dowling and Vamos (1993). When preferred squat depths are used, higher peak force outputs would be expected to result in increased jump height thereby resulting in a positive relationship. This investigation showed higher jump heights from squat depth that produced low peak force output, thereby resulting in a negative relationship. When subjects were allowed to squat deeper before jumping, the peak force value decreased in a linear fashion for both the static jump and countermovement jump. Similar results were observed in an investigation by Bobbert et al. (2008), which showed differences in the force-time curve depending on the squat depth used before performing the vertical jump. Time to complete the concentric phase was significantly longer at the deeper squat depths, with vertical peak force decreasing with deeper squat depths. This increase in ground contact time allowed for a higher vertical velocity to be reached before jumping. For peak force to be an accurate measure of comparing vertical jump capabilities within a given population, squat depth must be held constant throughout all jump trials for each subject and the entire sample.

In the current investigation when performing static jumps from a self-selected depth, subjects chose the depth that maximized both peak force and peak velocity thereby resulting in maximal power output. These results are interesting given that no feedback was given to the subjects regarding their squat depth or jump height. Results for the static jump trials cannot be attributed to an “optimal” depth that maximizes power, as a large range of preferred squat depths existed between the subjects. Despite having the highest peak power values, the heights attained from the self-selected depth were not the highest. When subjects were instructed to squat to the deepest squat depth (0.75 m), the resulting jump heights were significantly higher than from their self-selected depth and significantly lower than 0.75 m. Countermovement jump heights from the self-selected depth were significantly higher than 0.15 m, 0.30 m, and 0.45 m (Table 2).

**Discussion**

The current investigation demonstrates that relative net vertical impulse produced during the propulsive phase of the static jump and countermovement jump is a strong predictor of jump height. No known investigation has established a relationship between relative net vertical impulse and jump height. Hanson et al. (2007) examined net vertical impulse during jumping but no jump heights were reported. Feltner et al. (2004) reported that net vertical impulse during the propulsive phase of a countermovement jump increased with utilization of an arm-swing due to an increase in duration of that phase. Davies et al. (1983) reported that net vertical impulse was significantly lower in elderly males compared with younger males and that elderly males that had significantly lower jump heights. However, no correlations between relative net vertical impulse and jump height were reported in any of these investigations (Feltner et al., 2004; Hanson et al., 2007; Davies et al., 1983). As previously stated, the importance of net vertical impulse has been shown in investigations examining other high-velocity movements, such as sprinting (Hunter et al., 2005; Sleivert & Taingahue, 2004). The current investigation shows that relative net vertical impulse can be used to predict jump height regardless of squat depth. Therefore, relative net vertical impulse during the propulsive phase of the vertical jump may provide the most accurate way of explaining differences in jump performance across a group of individuals.

The influence of peak force on vertical jump height remains inconsistent within the literature. Peak force in an isometric leg extensor action has been shown to moderately correlate with jump height (Barnes et al., 2007). Dowling and Vamos (1993) also found that relative peak force was significantly correlated to vertical jump height ($r = .519$), yet explained less than $30\%$ of the variance observed. McBride et al. (2008) showed that peak concentric force significantly increased from a countermovement jump to a drop jump, yet jump height remained unaffected. Other investigations from our laboratory have shown that peak force generated during the concentric phase of the vertical jump is not correlated to jump height performance (Nuzzo et al., 2008). This investigation showed higher jump heights from squat depth that produced low peak force output, thereby resulting in a negative relationship. When subjects were allowed to squat deeper before jumping, the peak force value decreased in a linear fashion for both the static jump and countermovement jump. Similar results were observed in an investigation by Bobbert et al. (2008), which showed differences in the force-time curve depending on the squat depth used before performing the vertical jump. Time to complete the concentric phase was significantly longer at the deeper squat depths, with vertical peak force decreasing with deeper squat depths. This increase in ground contact time allowed for a higher vertical velocity to be reached before jumping. For peak force to be an accurate measure of comparing vertical jump capabilities within a given population, squat depth must be held constant throughout all jump trials for each subject and the entire sample.

Figure 5 — Peak vertical force and the peak vertical velocity for each squat depth during countermovement jump trials (preferred depth = 0.49 ± 0.06 m).
or exceed jump heights from their self-selected depth. Conversely, Domire and Challis (2007) reported that static jumps from a deeper squat depth did not result in greater jump heights and attributed the results to nonoptimal coordination during the jumps from the deeper squat depth. One reason for the discrepancy between the results from the current investigation and those found by Domire and Challis (2007) might be the differences in the deep squat depths. The deep squat used by Domire and Challis (2007) corresponded to the knee angle seen at the 0.45-m squat depth in this investigation, yet an increase in jump height above the self-selected depth was not observed until the 0.75-m squat depth. Domire and Challis had the subjects self-select their deeper depth, but if the subjects perceived that they would be unable to optimally coordinate a jumping pattern from a much deeper squat depth, they may be reluctant to select those depths.

The countermovement jump did not provide results similar to those observed for the static jump, with 0.15 m and 0.30 m resulting in higher peak power values than the self-selected depth. Interestingly, the depth for the countermovement jumps that produced the lowest jump heights (0.15 m) had the second highest peak power value. The discrepancy between maximal power outputs between self-selected squat depths for static jump and countermovement jump is unclear. One possibility may be that subjects selected a deeper squat depth for the countermovement jump because time was not a limiting factor during jump trials; they could take as long as necessary to complete a single jump. However, time is an integral component of many athletic endeavors, many of which require achieving the greatest jump height in a timely manner. Therefore, in those situations, subjects might select the depth that would achieve maximal jump height as quickly as possible. Bobbert et al. (1996) found that subjects lower their center of mass further during a countermovement jump compared with a static jump, which is supported by the results of the current study. The authors concluded that the increase in squat depth between the static jump and countermovement jump can be used to explain why countermovement jump heights are greater than static jump. By increasing squat depth, muscles are able to build up a higher level of active state and force before the start of shortening, thereby allowing greater work during the first phase of muscle shortening (Bobbert et al., 1996). This same mechanism might explain the differences between the self-selected depth and the depths that produced higher peak power outputs (0.15 m, 0.30 m) in the current study. By increasing squat depth, higher force was generated during the initiation of muscle shortening. However, because the force was then applied over a longer concentric phase, it did not result in a high peak force value. Since peak power is a product of the force and velocity generated during the concentric phase, depths that required large generations of force while still achieving a moderate level of velocity resulted in the highest peak power outputs.

Results from this investigation provide insight into the variation in kinetic and kinematic variables resulting from alteration of squat depth before performing a vertical jump. The primary finding of this investigation is that relative net vertical impulse determines jump height performance. Peak force is also a poor predictor of jump performance, as there can be large variation depending on squat depth. Squat depth affects peak performance variables, and this increases the difficulty of using these variables to assess vertical jump performance across a population. Therefore, increasing and monitoring relative net vertical impulse may be used to assess and improve vertical jump performance.

References


