A Descriptive Study of Lower-Body Strength and Power in Overweight Adolescents

James L. Nuzzo, Michael J. Cavill, N. Travis Triplett, and Jeffrey M. McBride

The primary purpose of this investigation was to provide a descriptive analysis of lower-body strength and vertical jump performance in overweight male (n = 8) and female (n = 13) adolescents. Maximal strength was tested in the leg press and isometric squat. Kinetic and kinematic variables were assessed in vertical jumps at various loads. When compared with females, males demonstrated significantly greater (p ≤ .05) absolute maximal strength in the leg press. However, when maximal strength was expressed relative to body mass, no significant difference was observed. There were no significant differences between males and females in vertical jump performance at body mass.

A recent report on the prevalence of overweight and obesity in the United States found that approximately 17% of children and adolescents are overweight and that 34% are at risk for being overweight (24). In addition, it has been estimated that by the year 2035, the risk of coronary heart disease in adults will increase between 5% and 16% because of the increasing trend of overweight in adolescents (4). As a result of these current trends, the majority of exercise-related research conducted on overweight children and adolescents has studied the effects of aerobic exercise training programs and diet modifications on body weight reduction and other measures of aerobic fitness (7,11,13,19,20,31). However, far less research has attempted to quantify anaerobic strength and power of the lower-body in overweight and obese children and adolescents (20,26,28).

Lower-body strength and power in overweight adolescents has been related to the ability to complete daily tasks such as climbing stairs (20) and rising from a chair (26). Greater levels of lower-body strength and power also help to propel the body mass during jumping activities (26) and as a result may affect the ability to participate in intermittent, anaerobic activities such as basketball and volleyball. However, the relationship between lower-body strength and vertical jump ability in overweight adolescents has undergone limited investigation (20). Maffiuletti and colleagues (20) discovered a significant, direct correlation between leg press one-repetition maximum (1RM) and vertical jump power in overweight...
adolescents. Direct comparisons between the lower-body strength and vertical jump ability of overweight male and female adolescents are also limited (20). No significant differences have been observed between genders for leg press 1RM, vertical jump power, or vertical jump height (20). However, the method used for quantifying the leg press 1RM by Maffiuletti and colleagues (20) was an estimated value based on performance of 15–20 repetitions with submaximal loads. Tests which use estimated 1RMs based on performance with submaximal loads are oftentimes inaccurate representations of actual maximal strength and should be interpreted with caution (22,32). Thus, the true maximal strength ability of male and female overweight adolescents, and the subsequent relationship with vertical jump performance, is still not fully understood. In addition, the methods used when reporting maximal strength in an overweight population still require further clarification. The maximal amount of weight lifted during a 1RM assessment is an indication of an individual’s absolute maximal strength. 1RM values can also be divided by an individual’s body mass to indicate relative maximal strength or a strength-to-body mass ratio (6,25,29,33). Thus, since relative maximal strength accounts for body mass, it may be better related to, and provide a better indication of, the ability of an overweight individual to move their body mass during physical activity when compared with absolute strength. A comparison between absolute and relative maximal strength assessments and their relationships with the ability to move a body mass, as in a vertical jump, has yet to be studied in a population of overweight adolescents.

Power output during vertical jumps is typically assessed when jumping at body mass with no additional load (20). However, previous investigations have implemented externally loaded vertical jumps to understand the load-power relationship and the load which maximizes power output in jumping (2,9,12,14,16,21,29,30). Identifying the optimal load for power has relevance for future training programs as common belief is that training at this load allows for the greatest improvements in power production (17). Conflicting results have been reported in healthy participants in regards to load which maximizes power in the vertical jump. Some studies have observed that body mass jumps maximize power (9,12,14) while others have reported that additional loading can help to maximize power (2,16,29,30). The conflicting data reported may be due to the absence of a body mass jump condition in some investigations (29,30). Thus, regardless of the population studied, determining the load which maximizes power still requires further investigation. In addition to serving as a method to determine the load which maximizes power, external loading can be used to simulate an overall increase in fat mass without accounting for distribution differences among body segments. Similar to fat mass, external loads are inert masses with no contractile characteristics. Thus, using external loading in scientific inquiry gives researchers the ability to simulate the effects of hypothetical increases in fat mass on vertical jump kinetics and kinematics. Due to the high amount of fat mass in overweight individuals it seems contradictory that further external loading would improve kinematics during human movement patterns. However, the only study to investigate the effects of external loading on power output in overweight subjects discovered that power was increased when external loads were implemented during stair climbing (18). The effect of external loading on vertical jump kinetics and kinematics has yet to be studied in an overweight population.
The purpose of this study was twofold: (1) to compare and provide a descriptive analysis of lower-body strength, vertical jump performance, and body composition in overweight male and female adolescents and (2) to assess the effects of external loading on vertical jump power output in overweight male and female adolescents. This descriptive report may help clarify the role that maximal strength and body composition have on the ability to move a body mass during physical activity in overweight adolescents.

Methods

Study Design

Participants participated in one testing session in which they completed an isometric squat test, leg press 1RM, and vertical jumps utilizing three different external loads. All participants completed a 5 min warm-up on a cycle ergometer at an intensity of one kilopond. Three trials of an isometric squat were then completed and analyzed for peak force and rate of force development (RFD). After an adequate recovery, participants completed single-repetition vertical jumps at three different external loads: 0 (i.e., body mass with no external load), 20, and 40% of isometric squat peak force (IPF; 0%IPF, 20%IPF, and 40%IPF). Peak force, peak velocity, peak power, and peak displacement were assessed during the vertical jumps to determine the effects of external loading on jump performance. Following the vertical jumps, leg press 1RM was assessed utilizing a sled apparatus. Comparisons between genders were made for all performance measures.

Participants

Eight male and 13 female adolescents (n = 21) participated in this investigation. Age and anthropometric measurements are summarized in Table 1. The participants in this investigation were required to complete the strength and power testing in partial fulfillment of a community-based exercise program designed for overweight adolescents. Inclusion into the program required that the participants have a body mass index (BMI) greater than or equal to the 85th percentile accord-

<table>
<thead>
<tr>
<th>Table 1 Age and Anthropometric Measurements for All Participants (n = 21), Males (n = 8), and Females (n = 13)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>All Participants</strong></td>
</tr>
<tr>
<td>Age (yrs)</td>
</tr>
<tr>
<td>Height (cm)</td>
</tr>
<tr>
<td>Weight (kg)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
</tr>
<tr>
<td>%Body Fat</td>
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</tbody>
</table>

*Note.* All data reported as mean ± SD; p-value for independent *t* test between genders. BMI = Body Mass Index
ing to sex and age (3). BMI values ranged from 25.0 kg/m² to 46.4 kg/m² with an average of 31.7 kg/m². In addition, body fat percentage was determined by dual energy x-ray absorptiometry (DEXA) using a Hologic QDR scanning device and software (New Bedford, Massachusetts, USA). The benefits and limitations of using DEXA for assessing body composition in a pediatric population have been discussed previously (1). Approval from the Appalachian State University Institutional Review Board for the Protection of Human Subjects was attained before data collection. Written informed consent was obtained from participants and their parents.

Maximal Strength Testing

Isometric Squat. Typically, vertical jump loads are determined as a percentage of a back squat 1RM (2,9,16,29,30). However, because of the untrained status of the participants in this study and their inexperience performing back squats, the isometric squat was used. The isometric squat has been found to significantly correlate with back squat 1RMs (5,33) and has also been used to determine external loading in a previous study (15). For the isometric squat test, participants were required to stand on a force plate (AMTI, BP6001200, Watertown, Massachusetts, USA) which was located inside of an adjustable rack. The rack height was adjusted so that a 100° knee angle was attained during the maximal push. Participants pushed up against an immovable bar as quickly and forcefully as possible for 3 sec. Three maximal trials were allotted with a 1 min rest period between trials. The trial in which maximal force was attained was used in further calculation and analysis.

Leg Press 1RM. Maximal strength in the leg press was attained using a sled apparatus. Before maximal attempts, participants completed a warm-up protocol based on an estimated 1RM. Estimated 1RMs were calculated as 2.25 × body weight. The warm-up sets consisted of six repetitions at 40%, 4 repetitions at 60%, two repetitions at 80%, and one repetition at 90% of the estimated 1RM. Participants were given up to five maximal attempts to achieve a 1RM. Maximal attempts were accepted if the participant lowered the sled and weights to a 90° knee angle and then pushed the weight up until full knee extension was achieved. Three minute rest periods were given between all sets.

Vertical Jump Testing

Participants completed vertical jumps with three relative external loads in a randomized order. IPF was converted to mass in kilograms by dividing by the acceleration rate due to gravity (9.81 m/s²). The vertical jump loads were determined as a percentage of that resultant mass and were thus equal 0%IPF, 20%IPF, and 40%IPF. Relative loading, as determined as a percentage of IPF, has been previously used when determining training loads for increasing vertical jump power (15). Participants were given three trials at each load, and the trial in which peak displacement was attained was used in the final analysis. Squat depth during the eccentric phase of the jump was self-selected by the participants to maximize jump height.
Measurement of Kinetic and Kinematic Variables

For the isometric squat, the force plate was zeroed to factor out each participant’s body weight as to determine relative loads based on their ability to produce force. Each trial for the isometric squat was analyzed for peak force and RFD at 200 ms based on force-time curves. The maximum force recorded from the force-time curve during the three second isometric trial was reported as IPF. The RFD was determined as the change in force from the start of the maximal push to the force at 200 ms and then divided by 200 ms.

The methods used for collecting and analyzing vertical jump performance have been described previously (9,10,23). All vertical jumps occurred on the force plate. During the jumps, participants were required to hold a bar on their shoulders and keep a constant downward pressure on the bar so that it would not move independently of the body. Attached to the bar were two linear position transducers (Celesco Transducer Products, PT5A-150, Chatsworth, California, USA) which were mounted on top of the rack, anterior, and posterior to the participant. Combining trigonometry using known displacements and the displacement measurements from the LPTs, vertical displacement and velocity were measured. Signals from the two LPTs and the force plate underwent rectangular smoothing with a moving average half-width of 12. The analog signals were collected at 1000 Hz using a BNC-2010 interface box with an analog-to-digital card (National Instruments, NI PCI-6014, Austin, Texas, USA). Peak force, peak velocity, and peak power were all assessed during the concentric phase of the vertical jumps. The beginning of the concentric phase was determined as the point at which the displacement-time curve became positive and was considered complete when the force-time curve became zero. The maximum force from the force-time curve during the concentric phase was determined to be the vertical jump peak force. Vertical jump peak velocity was measured by the change in bar displacement divided by the change in time during the concentric phase. Vertical jump peak power was determined by the concentric phase force multiplied by the concentric phase velocity. Peak displacement was determined as the difference between maximum bar displacement during the jump and the bar displacement while in the standing position. In addition, peak force and peak power were analyzed relative to each participant’s body mass. Custom-designed programs written in LabVIEW (National Instruments, Version 8.2, Austin, Texas, USA) were used for recording and analyzing the kinetic and kinematic variables in the isometric squat and vertical jump tests.

Statistical Analysis

Independent t tests were used to determine any significant differences in performance variables between genders. Pearson correlation coefficients were used to determine the relationships between performance variables. Correlations were analyzed with significance as $p \leq .05$ and $p \leq .01$. Intraclass correlation coefficients for within-session reliability for IPF and peak power during the vertical jumps were assessed using Cronbach’s alpha. A one-way analysis of variance (ANOVA) with Bonferroni posthoc tests was used to determine any significant differences ($p \leq .05$) between vertical jump variables across the three loads. After
running the ANOVA, the proportion of total variance attributed to the treatment was determined using the eta-squared statistic of effect size ($\eta^2 = \frac{\text{sum of squares between groups}}{\text{sum of squares total}}$) and the associated magnitude scale (small effect size = 0.01, medium effect size = 0.06, and large effect size = 0.14; 8). All statistical analyses were completed with a statistical software package (SPSS Version 14.0, SPSS Inc., Chicago, Illinois, USA).

Results

Test-retest data for within-session reliability of IPF was $r = .983$. Test-retest data for within-session reliability of vertical jump peak power at 0%IPF, 20%IPF, and 40%IPF was $r = .964$, 0.971, and 0.938, respectively.

Comparisons between males and females in maximal strength and RFD are located in Table 2. No significant differences were demonstrated between variables in the isometric squat. Absolute leg press 1RM was significantly greater in males when compared with females. When leg press 1RM was expressed relative to body mass using the 1RM-to-body mass ratio no significant difference was detected. When comparing males and females in measures of vertical jump performance only peak velocity at 40%IPF demonstrated a significant difference.

Correlations between strength assessments, body fat percentage, and 0%IPF vertical jump performance for males and females are presented in Tables 3 and 4, respectively. Absolute measures of strength (i.e., isometric squat peak force and leg press 1RM) were not significantly correlated with 0%IPF peak velocity, peak power, or peak displacement for either gender. However, when the strength measurements were expressed relative to body mass, significant correlations were demonstrated in males between relative isometric squat peak force and 0%IPF peak power and between relative leg press 1RM and 0%IPF peak velocity. For females, significant correlations were found between relative isometric squat peak

Table 2  Performance Variables in the Isometric Squat and the Leg Press 1RM

<table>
<thead>
<tr>
<th>Performance Variable</th>
<th>All Participants</th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO SQ PF (N)</td>
<td>685.7 ± 284.6</td>
<td>760.0 ± 321.0</td>
<td>640.0 ± 262.6</td>
</tr>
<tr>
<td>ISO SQ PF / BM (N/kg)</td>
<td>8.43 ± 3.30</td>
<td>8.98 ± 3.39</td>
<td>8.10 ± 3.35</td>
</tr>
<tr>
<td>ISO SQ RFD (N/s)</td>
<td>1157.8 ± 728.1</td>
<td>1045.9 ± 653.6</td>
<td>1226.6 ± 787.9</td>
</tr>
<tr>
<td>Leg press 1RM (kg)*</td>
<td>198.4 ± 52.2</td>
<td>208.2 ± 69.7</td>
<td>192.3 ± 40.1</td>
</tr>
<tr>
<td>Leg press 1RM / BM (kg/kg)</td>
<td>2.42 ± 0.46</td>
<td>2.40 ± 0.56</td>
<td>2.43 ± 0.42</td>
</tr>
</tbody>
</table>

Note. Values expressed as mean ± SD for participants (n = 21), males (n = 8), and females (n = 13). ISO SQ PF = isometric squat peak force; BM = body mass; RFD = rate of force development; 1RM = one-repetition maximum.

*Significant difference ($p \leq .05$) between males and females.
<table>
<thead>
<tr>
<th></th>
<th>0%IPF PF (N/kg)</th>
<th>0%IPF PV (m/s)</th>
<th>0%IPF PP (W/kg)</th>
<th>0%IPF PD (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>%Body fat</td>
<td>−0.679</td>
<td>−0.700</td>
<td>−0.748*</td>
<td>−0.513</td>
</tr>
<tr>
<td>ISO SQ PF (N)</td>
<td>0.755*</td>
<td>0.367</td>
<td>0.202</td>
<td>−0.131</td>
</tr>
<tr>
<td>Relative ISO SQ PF (N/kg)</td>
<td>0.764*</td>
<td>0.568</td>
<td>0.715*</td>
<td>0.437</td>
</tr>
<tr>
<td>ISO SQ RFD (N/s)</td>
<td>0.333</td>
<td>0.840**</td>
<td>0.695</td>
<td>0.738*</td>
</tr>
<tr>
<td>Leg press 1RM (kg)</td>
<td>0.158</td>
<td>0.198</td>
<td>−0.134</td>
<td>−0.134</td>
</tr>
<tr>
<td>Relative leg press 1RM (kg/kg)</td>
<td>0.358</td>
<td>0.751*</td>
<td>0.638</td>
<td>0.700</td>
</tr>
</tbody>
</table>

* Correlations significant at $p \leq .05$

** Correlations significant at $p \leq .01$

Note. 0%IPF = vertical jump at 0% isometric squat peak force; PF = peak force; PV = peak velocity; PP = peak power; PD = peak displacement; ISO SQ = isometric squat; RFD = rate of force development; 1RM = one-repetition maximum

Table 4 Correlates for Vertical Jump Performance in the Female Participants ($n = 13$)

<table>
<thead>
<tr>
<th></th>
<th>0%IPF PF (N/kg)</th>
<th>0%IPF PV (m/s)</th>
<th>0%IPF PP (W/kg)</th>
<th>0%IPF PD (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>%Body fat</td>
<td>−0.471</td>
<td>−0.882**</td>
<td>−0.869**</td>
<td>−0.698</td>
</tr>
<tr>
<td>ISO SQ PF (N)</td>
<td>0.509</td>
<td>0.392</td>
<td>0.460</td>
<td>0.434</td>
</tr>
<tr>
<td>Relative ISO SQ PF (N/kg)</td>
<td>0.836**</td>
<td>0.543</td>
<td>0.757**</td>
<td>0.498</td>
</tr>
<tr>
<td>ISO SQ RFD (N/s)</td>
<td>0.189</td>
<td>0.232</td>
<td>0.231</td>
<td>0.171</td>
</tr>
<tr>
<td>Leg press 1RM (kg)</td>
<td>0.112</td>
<td>0.118</td>
<td>0.040</td>
<td>0.097</td>
</tr>
<tr>
<td>Relative leg press 1RM (kg/kg)</td>
<td>0.741**</td>
<td>0.393</td>
<td>0.596*</td>
<td>0.256</td>
</tr>
</tbody>
</table>

* Correlations significant at $p \leq .05$

** Correlations significant at $p \leq .01$
force and 0%IPF peak power and between relative leg press 1RM and 0%IPF peak power.

When determining the effect of external loading on vertical jump peak force, no significant differences were found (Figure 1). The effect size for vertical jump peak force was \( \eta^2 = 0.09 \). Peak velocity was significantly decreased in all participants and females when comparing 0%IPF to 20%IPF and 40%IPF (Figure 2). Peak velocity for males was significantly different when comparing 0%IPF to 40%. The effect size for vertical jump peak velocity was \( \eta^2 = 0.38 \). The load which maximized power output in the vertical jump was found to be 0%IPF (Figure 3). Peak power decreased as the load was increased, and a significant difference was discovered between 0%IPF and 40%IPF for all subjects. The effect size for vertical jump peak power was \( \eta^2 = 0.12 \). Jump displacement was significantly greater in all subjects at 0%IPF when compared with 40%IPF (Figure 4). The effect size for vertical jump peak displacement was \( \eta^2 = 0.10 \).

**Discussion**

The results of this study have demonstrated that absolute leg press 1RM was significantly greater in overweight adolescent males when compared with overweight adolescent females. However, when leg press 1RM was expressed relative to body mass as a strength-to-body mass ratio, no significant difference was discovered between males and females. Similarly, no significant differences between males and females were discovered for 0%IPF kinetic and kinematic variables. In addition, it was observed that absolute measures of strength were not significantly

![Figure 1](image-url) — Vertical jump peak force for all participants, males, and females at loads equal to 0%IPF (i.e., body mass), 20%IPF, and 40%IPF. No significant differences were demonstrated between the three loads for any group of participants.
Figure 2 — Vertical jump peak velocity for all participants, males, and females at loads equal to 0%IPF (i.e., body mass), 20%IPF, and 40%IPF.
* Significant difference between vertical jump peak velocity at 0%IPF and 40%IPF. † Significant difference between vertical jump peak velocity at 0%IPF and at 20%IPF.

Figure 3 — Vertical jump peak power for all participants, males, and females at loads equal to 0%IPF (i.e., body mass), 20%IPF, and 40%IPF.
* Significant difference between vertical jump peak power at 0%IPF and 40%IPF.
correlated with vertical jump performance. However, when utilizing strength-to-body mass ratios, the relationships between lower-body strength and vertical jump performance became stronger. Furthermore, when assessing the effects of external loading on vertical jump performance, it was discovered that additional loads decreased performance such that maximal power was achieved with no external load.

Of the four measures of strength (absolute isometric squat peak force, relative isometric squat peak force, absolute leg press 1RM, and relative leg press 1RM) only absolute leg press 1RM demonstrated a significant difference between genders as males performed significantly better than females. However, when comparing males to females in vertical jump performance at 0%IPF, no significant differences were observed. Thus, although males had a greater level of absolute lower-body strength in the leg press, this was not indicative of their ability to perform a vertical jump. Consequently, absolute leg press 1RM was not significantly correlated with vertical jump performance. On the other hand, relative leg press 1RM was more strongly correlated with vertical jump performance. Previous investigations have also found that relative measures of maximal strength were strongly correlated to movements in which the body mass is propelled in some manner (i.e., jumping, sprinting, agility tests; 6, 25). Utilizing relative maximal strength values can be presumably even more appropriate in overweight populations because of the large amount of inert, fat mass which must be propelled during various movement patterns. In this investigation, strong inverse relationships were found between body fat percentage and vertical jump ability. Thus, although the absolute leg press 1RM may be an appropriate test for assessing absolute lower-body strength, it is not a good indicator of the functional ability to propel or move the body mass in an overweight population because of the
high percentage of body fat exhibited. It is thus suggested that future investigations provide relative values when testing maximal strength in overweight populations.

The load which maximizes power in a vertical jump has been the subject of recent debate (2,9,12,14,16,29,30). Similar to a study assessing power output in healthy male and female adolescents (12), the current investigation found that additional loading decreased peak velocity, peak power, and peak displacement during the vertical jump in overweight male and female adolescents. Power output was maximized when jumping at body mass due to the optimal combination of force and velocity. Other investigations utilizing healthy adult male and female participants have also found that power output was maximized at body mass (9,14,21). The conflicting results from other investigations regarding the load which maximizes power output may be due to methodological differences in the equipment used in measuring kinetic and kinematic variables (10), the various loading spectrums used (2,9,12,14,16,21,29,30), and the strength-to-body mass ratios of the participants (2,29). Furthermore, external loading can be used to represent temporary, artificial additions of inert, fat mass. In an overweight population it would seem obvious that further loading would hinder jump performance because of the already high percentage of body fat. However, it has been previously observed that overweight individuals increased power output when external loads were added to a stairclimbing task (18). The current investigation discovered that in the vertical jump, power output was not increased with external loading. The reason for differences between the effects of external loading on power output in stairclimbing and vertical jumping is not clear. Stairclimbing is composed primarily of a concentric phase (27) while vertical jumping is composed of a substantial eccentric phase before the concentric phase (23). Thus, it could be speculated that power output during the concentric phase of externally loaded movements is dependent on the absence or presence of an eccentric phase. An additional consideration for measuring power output in an overweight population is the use of deloading. Although temporary deloading of a body mass has not been shown to be beneficial for enhancing power output in a healthy population of adult males (21), the effects of deloading on power output in a population with a high percentage of body mass has yet to be investigated.

**Conclusion**

In summary, when measuring maximal strength in overweight adolescents it appears more valuable for the researcher and practitioner to report relative strength values rather than absolute values. Relative strength values indicate not only the maximal strength of the adolescent but also the ability to use that strength to move the body mass in various activities. In overweight adolescents, the relationships between body composition, maximal strength, and vertical jump ability indicate that a decreased body fat percentage and an increased strength-to-body mass ratio are beneficial for jumping tasks. To improve body fat percentage and strength-to-body mass ratios in overweight adolescents, concurrent diet modification, aerobic exercise, and resistance training programs are recommended. In addition, recreational exercise modalities which involve jumping such as basketball and volley-
ball are recommended not only because of their metabolic demand but also because of their ability to maximize power output during exercise.

References