Effect of Rest Interval Length on Bench Press Performance in Boys, Teens, and Men

Avery D. Faigenbaum, Nicholas A. Ratamess, Jim McFarland, Jon Kaczmarek, Michael J. Coraggio, Jie Kang, and Jay R. Hoffman

The purpose of this study was to assess the lifting performance of boys ($N = 12; \text{age} 11.3 \pm 0.8 \text{yr}$), teens ($N = 13; \text{age} 13.6 \pm 0.6 \text{yr}$), and men ($N = 17; \text{age} 21.4 \pm 2.1 \text{yr}$) to various rest interval (RI) lengths on the bench press exercise. Each subject performed 3 sets with a 10 repetition maximum load and a 1, 2, and 3 min RI between sets. Significant differences in lifting performance between age groups were observed within each RI for selected sets with boys and teens performing significantly more total repetitions than adults following protocols with 1 min (27.9 $\pm$ 3.1, 26.9 $\pm$ 3.9, and 18.2 $\pm$ 4.1, respectively), 2 min (29.6 $\pm$ 1.0, 27.8 $\pm$ 3.5, and 21.4 $\pm$ 4.1, respectively) and 3 min (30.0 $\pm$ 0.0, 28.8 $\pm$ 2.4, and 23.9 $\pm$ 5.3, respectively) RIs. Significant differences in average velocity and average power between age groups were also observed. These findings indicate that boys and teens are better able to maintain muscle performance during intermittent moderate-intensity resistance exercise as compared with men.

Resistance training (RT) has been shown to be a safe and effective method for enhancing muscle strength, power, and endurance in children, adolescents, and adults (5,10). However, the act of RT itself does not ensure optimal gains in performance will occur. Rather, the systematic structuring of program variables (e.g., intensity, volume) along with individual effort and qualified instruction will determine the outcomes associated with RT. In addition, the length of the rest interval (RI) in between sets and exercises is of primary importance to coaches, teachers, athletes, and researchers (36). In adults, the RI between sets has been shown to affect performance of subsequent sets (21,37), strength improvements (32), and metabolic and hormonal responses to an acute bout of resistance exercise (17,25). We have shown a continuum of responses where bench press performance was reduced in adults in proportion to reductions in RIs between sets (25). Since acute force and power production may be compromised with short RIs, longer RIs of at

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least 2–3 min for core, multiple-joint exercises are recommended during adult resistance training programs (15,18).

However, RT recommendations for adults may not be consistent with the needs and abilities of younger populations. Studies have shown faster recovery rates from exercise in children than adults (9,27). It has been reported that children (compared with adults) have a faster heart rate recovery (13), lower peak lactate concentrations (11,26), higher oxidative capacity (35), better acid-base regulation (28), and a tendency toward faster phosphocreatine (PCr) resynthesis (19,35) following high-intensity exercise. Recently, Zafeiridis and colleagues (40) showed that recovery following high-intensity 30- and 60-s isokinetic exercise was faster in boys than in teens and men. Indeed, performance and physiological functions appear to recover faster in children than in teens and adults following high-intensity exercise.

Despite these observations, the effects of age and recovery duration on strength performance in children and teenagers are poorly understood. Most studies quantifying age-related differences in muscle fatigue have used high-intensity cycle ergometry (3,11,13,26); only two studies examined resistance exercise (33,40); and no studies have used RT protocols consistent with current recommendations for children and teens. Because recovery from high-intensity cycle ergometry or isokinetic exercise may differ from resistance exercise, further research is needed to quantify strength performance to RI manipulations in children, teenagers and adults. Given the acceptance of youth RT by medical and fitness organizations (1,2,6), this information is valuable to teachers, coaches, and health professionals who design and implement youth RT programs.

Therefore, the purpose of this investigation was to quantify bench press performances of boys, teens, and men to various RI lengths. In addition, there is a paucity of data examining RI effects on kinetic and kinematic profiles of a resistance exercise set on a repetition-by-repetition basis. Thus, a secondary purpose was to investigate the effects of RI length on kinetic and kinematic parameters (power, velocity) in boys, teens, and men. Due to growth- and maturation-related differences in response to physical exertion, it was hypothesized that boys and teens would recover faster than adults from multiset resistance exercise with different RIs.

**Methods**

**Participants**

Twelve boys (11.3 ± 0.8 yr), 13 teens (13.6 ± 0.6 yr), and 17 men (21.4 ± 2.1 yr) volunteered to participate in this study. All participants were healthy and had RT experience as part of physical education classes, sports conditioning, after-school programs, or recreational fitness workouts. Most participants participated regularly (at least 2–3×/week) in basketball, baseball, or soccer. Participant descriptive characteristics are shown in Table 1. All adults and parents of the boys and teens completed a medical history questionnaire. The exclusionary criteria used were: (a) subjects with a chronic cardiac, respiratory, renal, or metabolic disease and (b) subjects with an orthopedic limitation. No participant was taking any med-
ication or nutritional supplement known to affect resistance exercise performance. The methods and procedures were approved by the Institutional Review Board for use of human participants at the College, and all adults and parents of boys and teens signed an informed consent form. In addition, each boy and teen signed a child assent form.

### Study Protocol

To examine the effects of age and RI length on lifting performance, a group of boys, teens, and men participated in three different bench press protocols [3 sets of 10 repetitions with a 10 repetition maximum (RM) load with 1-, 2-, and 3-min RIs between sets] in random order on nonconsecutive days. This was a cross-over design whereby each participant served as their own control. A 10 RM exercise intensity [e.g., ~75% of one repetition-maximum (1 RM)] was selected because it is used in many youth and adult RT programs (8,18). RIs of 1-, 2-, and 3-min RIs were used because most RT programs recommend a range of RIs between 1–3 min (6,15). Only one upper body exercise was used because the intent of this study was to quantify lifting performances of boys, teens, and men to various RI lengths. Total repetitions completed, average velocity, average velocity fatigue rate (FR), average power, and average power FR were measured. Participants were asked to abstain from vigorous exercise activity for 48 hr before each session. Each participant completed all study procedures within two weeks. All participants were evaluated by researchers who had experience testing and training youth and adults, e.g., were certified strength and conditioning specialists.

Participants’ height and body mass were measured in the first session using a wall-mounted stadiometer and electronic scale, respectively. A pediatrician determined the pubertal stage of boys and teens according to pubic hair development (34). Subsequently, proper form and technique of the bench press were reviewed and practiced by all participants. Participants were required to keep their head and hips in contact with the bench, lightly touch the barbell to their chest, and fully extend their arms to complete a repetition. In addition, participants performed each repetition at a self-selected velocity and used the same hand position for each

### Table 1  Physical and Performance Characteristics of the Subjects

<table>
<thead>
<tr>
<th></th>
<th>Boys (N = 12)</th>
<th>Teens (N = 13)</th>
<th>Men (N = 17)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age (y)</strong></td>
<td>11.3 ± 0.8</td>
<td>13.6 ± 0.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>21.4 ± 2.1&lt;sup&gt;b,c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Tanner Stage</td>
<td>1–2</td>
<td>3–4</td>
<td></td>
</tr>
<tr>
<td><strong>Height (cm)</strong></td>
<td>151.9 ± 9.8</td>
<td>167.1 ± 11.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>178.5 ± 7.8&lt;sup&gt;b,c&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Body Mass (kg)</strong></td>
<td>49.1 ± 11.0</td>
<td>68.2 ± 16.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>81.9 ± 11.1&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>1 RM BP (kg)</strong></td>
<td>27.1 ± 7.7</td>
<td>46.0 ± 11.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>101.1 ± 16.6&lt;sup&gt;b,c&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>10 RM BP (kg)</strong></td>
<td>20.1 ± 5.6</td>
<td>33.4 ± 9.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>77.3 ± 13.1&lt;sup&gt;b,c&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Relative Strength (%)</strong></td>
<td>55.7 ± 13.0</td>
<td>68.9 ± 14.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>124.3 ± 18.8&lt;sup&gt;b,c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

*Note: RM = repetition maximum; BP = bench press; <sup>a</sup>P < .05 boys vs. teens; <sup>b</sup>P < .05 boys vs. men; <sup>c</sup>P < .05 teens vs. men; Values are means ± SD*
trial which was determined by the distance between the index finger and bar striations.

**Strength Testing**

Approximately 2–3 days following initial screening, each participant’s 1 RM bench press strength was assessed using a standard protocol (16). Briefly, a warm-up set of five repetitions was performed using a light load (50% of the perceived 1 RM). After a 1-min RI, three repetitions were performed with a moderate load (70% of perceived 1 RM). Subsequently, 3–4 maximal trials were performed to determine the 1 RM with 2–3 min RI between trials. A complete range of motion and proper technique were required for each successful 1 RM trial. Failure was defined as an incomplete trial (limited ROM) on at least two attempts separated by at least 2 min. All strength measurements were attained by the same researchers using standard equipment. Adults used a 20.5 kg bar and young participants used a 6.8 kg bar. Verbal encouragement was given throughout all testing procedures. Test-retest reliabilities for 1 RM testing were $R > .93$ (7,16). Relative strength was calculated as 1 RM / body mass.

At least 10 min after the determination of the 1 RM, each participant’s bench press 10 RM was determined. Following an initial attempt using 75% of each subject’s 1 RM, the load was increased or decreased to determine the maximum resistance which could be lifted throughout the full ROM using proper form for 10 repetitions only. Two or three trials were performed to determine the 10 RM with 2–3 min RI between trials.

**Bench Press Protocols**

Three bench press protocols were completed; each consisted of performing the bench press for three sets of 10 RM load to volitional exhaustion using a self-selected cadence. The RI between sets was 1, 2, or 3 min and testing order was randomized. Participants were only permitted to sit, stand, or walk in between sets. Before initiation of each protocol, participants performed a standard warm-up of 5 min of low-intensity aerobic exercise and calisthenics followed by one set of the bench press for five repetitions with 25% of their 10 RM. Verbal encouragement was provided to all participants during each set.

The number of repetitions completed each set was recorded. Average power (AP) and velocity (AV) for each repetition were measured using a Tendo unit (Model V-104, Tendo Sports Machines, Trencin, Slovak Republic). The Tendo unit is a computerized system consisting of a transducer that enables the measurement of bar displacement. The free end of the unit was attached to one end of the barbell while the platform was positioned linearly underneath the barbell. Since time was measured by the Tendo unit, bar velocity was calculated for each repetition. Subsequently, inputting the load on the bar enabled calculation of AP for each repetition. Fatigue rates for AV and AP were calculated. Average velocity fatigue rate was determined by $[\text{AV set } 1—\text{set } 3 / \text{AV set } 1 \times 100]$ and AP fatigue rate was determined by $[\text{AP set } 1—\text{set } 3 / \text{AP set } 1 \times 100]$ for all sets and RIs. Each training session was completed within 30 min. Test-retest reliabilities for AV and AP were $R = .87–0.94$. 
Statistical Analysis

Standard statistical methods were used to calculate means and standard deviations. Comparisons of performance characteristics among different age groups were made using one-way analysis of variance (ANOVA). A two-way (group × RI) ANOVA with repeated measures was used to examine the effects of age and RI on lifting performance. When a significant $F$ value was achieved, post hoc comparisons were accomplished via a least significant difference (LSD) test. Pearson-product moment correlations were used to examine relationships between 1 RM data and total repetitions completed for all RIs. Statistical significance was set at $p \leq .05$ and all analyses were performed using SPSS statistical package (Version 14.0, SPSS, Inc, Chicago, IL).

Results

Participant physical and performance characteristics are presented in Table 1. Ten RM strength for boys, teens, and men corresponded to 74.1 ± 3.0%, 73.3 ± 3.4%, and 76.6 ± 2.5%, respectively, of the 1 RM. The average number of repetitions completed in all sets by boys, teens, and men for all RIs are presented in Table 2. Significant differences in lifting performance between age groups were observed within each RI for selected sets. Comparisons between age groups revealed that boys and teens performed significantly more total repetitions for three sets than adults following exercise protocols with 1-, 2-, and 3-min RIs. Significant differences were also observed for each RI for selected sets.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Average Number of Repetitions Completed in All Sets by Boys, Teens and Men for All Rest Intervals (RI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Boys ($N = 12$)</td>
</tr>
<tr>
<td>1-Min RI</td>
<td></td>
</tr>
<tr>
<td>Set 1</td>
<td>10.0 ± 0.0</td>
</tr>
<tr>
<td>Set 2</td>
<td>9.2 ± 1.4</td>
</tr>
<tr>
<td>Set 3</td>
<td>8.7 ± 2.1 $b,d$</td>
</tr>
<tr>
<td>TOTAL</td>
<td>27.9 ± 3.1</td>
</tr>
<tr>
<td>2-Min RI</td>
<td></td>
</tr>
<tr>
<td>Set 1</td>
<td>10.0 ± 0.0</td>
</tr>
<tr>
<td>Set 2</td>
<td>10.0 ± 0.0</td>
</tr>
<tr>
<td>Set 3</td>
<td>9.6 ± 1.0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>29.6 ± 1.0</td>
</tr>
<tr>
<td>3-Min RI</td>
<td></td>
</tr>
<tr>
<td>Set 1</td>
<td>10.0 ± 0.0</td>
</tr>
<tr>
<td>Set 2</td>
<td>10.0 ± 0.0</td>
</tr>
<tr>
<td>Set 3</td>
<td>10.0 ± 0.0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>30.0 ± 0.0</td>
</tr>
</tbody>
</table>

Note. $a P < .05$ Set 1 vs. Set 2; $b P < .05$ Set 1 vs. Set 3; $c P < .05$ Set 2 vs. Set 3; $d P < .05$ Boys vs. Men; $e P < .05$ Teens vs. Men. Values are mean ± SD.
Results for AV across all RIs are presented in Table 3. Significant differences in AV between groups were observed within each RI for selected sets. Significant differences in AV within each age group were observed during 1-min RI. In boys, teens and men, AV was significantly greater during set 1 than sets 2 and 3, and AV was significantly greater during set 2 than set 3.

Results for AV FR for boys, teens, and men across all RIs are presented in Table 4. Average velocity FR was significantly greater for teens and men than boys during 1-, 2-, and 3-min RIs. Significant differences within each age group were observed for AV FR between RIs.

Results for AP across all RIs are presented in Table 5. Average power for teens and men were significantly greater than boys, and AP for men was significantly greater than teens. Comparisons between age groups revealed that mean AP across three sets for teens and men were significantly greater than boys during all RIs, and mean AP for men was significantly greater than teens across all RIs.

Results for AP FR across all RIs are presented in Table 4. Average power FR was significantly greater for men than boys during 2-min RI. Significant differences within each age group were observed for AP FR between RIs. Across all age groups, a significant negative correlation was observed between 1 RM strength and total repetitions completed following testing protocols with 1-, 2-, and 3-min RIs ($r = -0.63$ to $-0.80$).
The main findings from the current study indicate that boys and teens were able to perform significantly more repetitions with a 10 RM load on the bench press for three sets with 1-, 2-, and 3-min RIs compared with men. These findings support our hypothesis that boys and teens are able to recover faster than men from moderate-intensity resistance exercise. To our knowledge, this was the first study to examine the acute responses to resistance exercise in boys, teens, and men using three different RI lengths.

**Table 4** Average Velocity (Upper) and Power (Lower) FR for Boys, Teens and Men for All Rest Intervals (RI)

<table>
<thead>
<tr>
<th>Rest Interval</th>
<th>Boys (N = 12)</th>
<th>Teens (N = 13)</th>
<th>Men (N = 17)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-Min RI</td>
<td>17.4 ± 9.2</td>
<td>36.5 ± 14.5</td>
<td>38.2 ± 10.8</td>
</tr>
<tr>
<td>2-Min RI</td>
<td>5.9 ± 14.5</td>
<td>29.8 ± 23.2</td>
<td>22.9 ± 18.4</td>
</tr>
<tr>
<td>3-Min RI</td>
<td>4.7 ± 12.5</td>
<td>18.8 ± 15.5</td>
<td>16.5 ± 16.2</td>
</tr>
</tbody>
</table>

**Table 5** Average Power for Each Set Performed by Boys, Teens and Men for All Rest Intervals (RI)

<table>
<thead>
<tr>
<th>Rest Interval</th>
<th>Boys (N = 12)</th>
<th>Teens (N = 13)</th>
<th>Men (N = 17)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-Min RI</td>
<td>75.4 ± 19.9</td>
<td>158.3 ± 53.5</td>
<td>284.7 ± 47.2</td>
</tr>
<tr>
<td>2-Min RI</td>
<td>63.1 ± 17.5</td>
<td>125.5 ± 50.2</td>
<td>206.2 ± 46.3</td>
</tr>
<tr>
<td>3-Min RI</td>
<td>58.7 ± 16.1</td>
<td>104.2 ± 45.2</td>
<td>172.9 ± 53.6</td>
</tr>
</tbody>
</table>

**Discussion**

The main findings from the current study indicate that boys and teens were able to perform significantly more repetitions with a 10 RM load on the bench press for three sets with 1-, 2-, and 3-min RIs compared with men. These findings support our hypothesis that boys and teens are able to recover faster than men from moderate-intensity resistance exercise. To our knowledge, this was the first study to examine the acute responses to resistance exercise in boys, teens, and men using three different RI lengths.
The RI length is an important RT variable because it dictates the amount of recovery that takes place between sets and exercises. The results of the present investigation indicated that boys and teens were able to maintain lifting performance better than adults during multiset resistance exercise protocols with 1-, 2-, and 3-min RIs. A continuum was identified such that the decline in lifting performance across three sets for each RI was most pronounced in men and significantly less pronounced in teens and boys. Although the magnitude of the effect of RI length on lifting performance between age groups was most evident following 1- and 2-min RIs, a similar trend was observed following 3-min RI with boys and teens performing significantly more repetitions than men on the third set. As such, boys and teens were able to maintain lifting performance over three sets with 3-min RI whereas lifting performance in men declined significantly from 10.0 repetitions on set 1 to 6.0 repetitions on set 3.

The results of the present investigation are consistent with previous studies which have shown acute performance reductions with shorter RI lengths during resistance exercise in adults (14,21,25,38). Ratamess and colleagues reported a continuum of performance reductions in resistance-trained adults on the bench press (5 sets with 75% or 85% of 1 RM), with lifting performance maintained during the first 3–4 sets with 3–5 min RIs but reduced substantially (up to 55%) with a short RI (< 2 min; 25). Similarly, other studies have shown that the number of repetitions performed may be compromised with short RIs (< 1 min; 31, 37, 39).

Although few data involving children, teens, and adults are available for comparison, the ability of boys to resist fatigue to a greater extent than adults during several repeated exercise bouts is consistent with others who examined age-related differences in the rate and magnitude of recovery from high-intensity sprint cycling (13,26) and running sprints (29,30). Zafeiridis et al. reported that recovery was faster in boys than in teens and men during high-intensity 30-s (4 sets × 18 repetitions, 1-min RI) and 60-s (2 sets × 34 repetitions, 2-min RI) maximal isokinetic knee extensions-flexions (40). In contrast, Soares et al. reported bench press repetition number (5 sets with 80% 1 RM, 90-s RI) decreased similarly in children and men; however, maximum isometric force decreased significantly immediately after exercise in adults but not children (33). While differences in exercise protocol design, participants motivation, and familiarization with testing procedures could explain some of these differences, most data indicate children are better able to maintain performance during repeated moderate-to-high intensity exercise bouts than adults.

Due to considerable age-related differences in body size and muscle mass, it is not possible to use identical absolute RM loads for studies involving boys, teens and men. In our study, all participants performed a 1 RM test following standardized procedures and then performed several sets with a predetermined 10 RM load which was approximately 75% of their 1 RM. Although significant age-related differences in maximum strength were expected, significant age-related differences in relative strength between boys (55.7%), teens (68.9%), and adults (124.3%) were observed. Moreover, significant differences in AP among all age groups were observed for all sets and RIs with men producing the highest values and boys producing the lowest values (Table 5). Similar trends were observed
among age groups for AV whereby men had a higher mean AV than teens for all RIs and teens had a higher mean AV than the boys during 1-min RI (Table 3).

It is conceivable that the ability of boys and teens to recover faster than men from multiset RT may be largely due to maturity-related differences in force and power production. In the current study, boys and teens may have had superior performance maintenance over three sets because they had a lower level of strength, i.e., a lower initial level of strength may yield less potential absolute reduction in performance. Further support of this contention was observed by the significant negative correlations seen between 1 RM bench press strength and the total number of repetitions performed during 1-, 2-, and 3-min RIs for all pooled age groups ($r = \text{-.63 to -.80}$). Thus, our results showed participants with higher levels of maximal strength performed fewer repetitions over three sets than those subjects with lower levels of strength.

Unique to the current study was the measurement of bar velocity and power during each repetition of the bench press. These kinematic and kinetic measures provided additional performance characteristics of bench press performance and the subsequent changes that occurred with various RIs. It is possible that reductions in power and velocity during a set can occur despite a lack of change in total repetition number when a self-selected cadence is used. We have previously shown in adult men that mean force and power obtained during six sets of the squat (with 75% of 1 RM for 10 repetitions using 2-min RI with a self-selected cadence) decreased proportionally from set to set despite participants’ ability to maintain repetition number for at least the first 2–3 sets (unpublished observations). Therefore, RI length can affect other parameters of acute lifting performance that are not reflected by the total number of repetitions successfully performed.

Highest AVs were observed in teens compared with boys and men during the first set of each protocol. This finding was interesting in that all age groups performed each protocol with similar relative loading (10 RM or 75–76% of 1RM). Although absolute loading was quite different between age groups, our findings may indicate a technical variation in bench press performance between participants of different ages, i.e., a preference for teens to accelerate the bar to a higher degree in a nonfatigued state. It is unclear as to why this occurred but may be related to greater absolute loading in adults (i.e., a need for greater control with heavier loading or perhaps less experience with the bench press in boys).

Subsequent set performance was significantly affected by RI length in all age groups. During 1-min RI, all age groups showed significant reductions in AV for sets 2 and 3 compared with set 1 (with adults showing the largest reduction). When 2- and 3-min protocols were performed, only the adults showed significant reductions in AV during sets 2 and 3. Upon examination of AV FR, boys showed significantly lower FRs than teens and men for all RIs. These results coincide with the repetition number data as boys AV performances were less affected by RI length than teens and men. Because teens showed the highest AVs in the nonfatigued state (set 1), it was not surprising that their FRs were similar to men. The lower FRs observed in boys may be explained by a few possibilities. It has been shown that boys demonstrate greater recovery rates than teens and adults (40). Thus, enhanced recovery in boys could be due, in part, to the lower AV FRs observed across all RIs. Because boys’ AV was lower than teens during set 1, there would be less potential for further reductions thereby decreasing the FR. This could reflect, in part, less
experience or familiarity with the exercise compared with teens and adults as well as it could be speculated that less familiarity led to a self-imposed slower velocity of lifting. However, further research is needed to elucidate factors involved in lower FRs observed in boys compared with teens and adults.

Likewise, declines in AP over three sets for all RIs was smaller in boys as compared with teens and men which are consistent with others who examined the decline in power following maximal knee extensions-flexions in similar age groups (40). In our study, AP FR was higher following 1-min RI than 2- and 3-min RI protocols for all age-groups. Comparisons between age groups revealed that following 2-min RI the AP FR for boys was significantly lower than men and no significant reductions in AP were observed in boys when 2- and 3-min RIs were used. These results also demonstrate enhanced recovery ability for boys compared with teens and men, and that RI length significantly affects AP per set in all age groups when 1-min RI is used but only in teens and men when 2- and 3-min RIs are used. As expected, AP was lowest in boys and highest in men. This finding can most likely be explained by differences in maturity as a continuum was observed where boys had the least magnitude of maximal strength and men were significantly stronger than teens and boys. Because power is the product of force and velocity, it appeared that the force differential between age groups was the most significant factor as only few differences in AV were observed between groups.

In adults, a short RI limits the magnitude of recovery and participants perform subsequent sets in a semifatigued state. This may result in greater metabolite (e.g., H+ ions) elevations and increase reliance on slow-twitch muscle fibers (since fast twitch fibers are more fatigable and less oxidative), which consequently alter recruitment patterns and reduce force production (37). Slower rates of strength gain have been reported in adults who train with short RI due to the reduction in loading capacity (24,32). This is especially true when participants’ resistance train with a RI less than 2 min as it was recently shown that similar strength gains may be attained using 2- and 4-min RIs (39). However, since children have been shown to have a higher relative percentage of slow-twitch muscle fibers in certain muscles than adults, they may display greater resistance to fatigue during sustained contractions (20,22). It is also possible that age-related differences in the ability to recruit and use higher-hierarchy Type II motor units may contribute to age-related differences in the ability to recover from physical exertion (9).

Qualitative musculometabolic differences between boys, teens and men may contribute to age-related differences in performance and recovery capacity. It has been reported that children have superior ability to maintain performance during repeated bouts of high-intensity exercise primarily due to enhanced oxidative and glycolytic efficiency (19,35). Hebestreit et al. reported that after a 30-s Wingate anaerobic test boys were able to repeat their performance after 2-min RI whereas adults were unable to do so after 10-min RI (13). When compared with adults, children have been shown to have a faster rate of phosphocreatine resynthesis (35), superior acid-base regulation (28), and lower peak lactate concentrations after exercise (4). While data comparing children and teenagers is scarce, Petersen et al. reported no significant maturity-related differences in muscle metabolism during high-intensity exercise in prepubertal and pubertal girls (23). In the present investigation, no significant differences in lifting performance between boys and
teens were observed, although age-related differences in AV and AP were noted. Although speculative, there may be a gradual transition during the developmental years in the ability to resist fatigue and maintain exercise intensity.

Of note, the type and intensity of exercise performed should be considered when examining the recovery process. A majority of studies examining age-related differences in recovery employed high-intensity cycling protocols or maximal isokinetic tests which required participants to start each interval or set with maximal effort (13,26,40). Unlike other studies, our protocol did not require participants to begin each set with maximal effort, but rather perform as many repetitions as possible until ensuing muscle fatigue limited performance. The ability to maintain performance during RT with 10 RM loading compared with an “all out” 30-s sprint may impose different metabolic demands and require different strategies for recovery.

In conclusion, this study showed that if three sets of the bench press are performed with a 10 RM load and strength training is the primary goal: (1) men may need RIs of at least 3 min between sets; (2) teens may require RIs of at least 2 min; and (3) boys may only require RIs of at least 1 min to minimize loading reductions and attain the highest possible lifting volume. Our data indicate that RT recommendations for RI length may need to be age-specific in addition to the training goals. Although we examined one intensity, it is likely that similar RIs may be appropriate for lower and higher RT intensities, provided each set is performed to volitional fatigue. Additional research is required to better understand age-related differences in RT performance and to examine mechanisms that may be responsible for maturity-related differences in the recovery of force, velocity, and power in untrained and trained individuals.

References


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