Effect of Rest Interval on Neuromuscular and Metabolic Responses Between Children and Adolescents

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The purpose of this study was to compare the effect of different rest intervals and contraction velocities on muscle recovery following resistance exercise. 18 children (11.1 ± 0.52 yrs) and 19 adolescents (15.8 ± 0.49 yrs) performed three sets of 10 isokinetic repetitions at 60°/s and 180°/s. The work-to-rest ratio (W/R) was 1:2 and 1:4 for 60°/s, and 1:6 and 1:12 for 180°/s. ANOVA revealed that children demonstrated no significant decline in PT from the first to third set with any rest interval, but there was a significant (p < .05) decline for adolescents when a W/R of 1:2, 1:4 and 1:6 were used. Adolescents demonstrated significantly greater blood lactate (BLa) concentrations than children after three sets of resistance exercise. The present study indicates that adolescents may require longer rest intervals to recover full PT when compared with children.

Resistance to fatigue and the ability of muscle to recover during repeated sets of high-intensity intermittent exercise are important attributes of neuromuscular function and have been associated with biological maturation (8,34). Resistance training has been shown to improve strength, power, local muscular endurance, and resistance to fatigue in different populations (1). Furthermore, optimally designed resistance training programs are based on scientific principles that ensure correct manipulation of critical training variables. This is normally achieved by altering
frequency, volume, intensity, exercise type, between-set rest intervals (RI) and other variables (1,22).

An adequate RI is necessary to offset the detrimental effects of fatigue and facilitate muscle recovery. The acute effects of different between-set RI on muscle fatigue have been extensively studied in young and old men and women (3,5,7,26,28,29,38). However, RI recommendations for adults may not be consistent with the needs and abilities of younger populations due to growth and maturation-related differences in the response to resistance exercise (11). According to Halin et al. (16), children’s neuromuscular activation (motor unit recruitment and firing rate) is not complete, and is lower when compared with adolescents and adults. Furthermore, related to the size principle of motor unit recruitment, children are less capable of activating the more fatigable Type II motor units than adults during voluntary contractions (16). This mechanism could therefore have some influence on muscle fatigability and recovery in children.

There is limited information on the effect of different RI during resistance exercise in children and adolescents. To our knowledge, only one study has examined the effects of RI length on strength performance in these populations (10). In addition, potential mechanisms for maturational effects on fatigue have been linked in part to glycolytic metabolism (12,34,35). In addition, blood lactate (BLa) assessment has been an important variable used to better understand glycolytic metabolism during exercise and fatigue. Increased BLa concentration and H+ lowers blood pH, which in turn may dissociate Ca2+ from troponin, disturb crossbridge formation and decrease the force generation capacity of muscle (41). Therefore, the purpose of the current study was to compare the effect of different between set RI’s on strength and BLa, between different muscle contraction velocities, and between children and adolescents.

Methods

Experimental Procedures
To test the effect of RI length on knee extensor peak torque (PT) and total work (TW), subjects performed an isokinetic training protocol on two separate days with a minimum of 48 and a maximum of 72 hr between test sessions. They performed three sets of 10 isokinetic concentric repetitions at 60°·s⁻¹ and 180°·s⁻¹ on each of the two visits with the RI (60 and 120 s) varying between visits. The order of the RI conditions was counterbalanced. The RI and number of sets were selected according to the recommendations for youth resistance training from the National Strength and Conditioning Association (11).

Subjects
This study was approved by the University Institutional Review Board. Eighteen boys (age 11.1 ± 0.52 yrs; mass 32.9 ± 3.32 kg; height 142.6 ± 4.78 cm, Tanner stage 1 and 2) and 19 male teens (age 15.8 ± 0.49 yrs; mass 60.4 ± 3.21 kg; height 176.2 ± 4.56 cm, Tanner stage 4) nonresistance trained subjects (i.e., no prior experience in resistance training) volunteered for the study. Most participants were involved in recreational physical activity such as swimming, basketball, or soccer. They were
randomly selected from respondents to fliers distributed in public schools, and by word-of-mouth. They were informed of the purpose, procedures, possible discomforts, risks, and benefits of the study before signing an informed assent document. Parental written informed consent was also required. Participants were excluded from the study if they reported any history of cardiovascular or orthopedic disease.

**Warm Up and Familiarization**

Subjects warmed-up on a cycle ergometer at 25–50 Watts for five min at a self-selected cadence. After warm-up, they were seated on the isokinetic dynamometer and actively warmed-up the quadriceps muscles by performing 10–12 submaximal knee extension repetitions at 300°·s⁻¹. For familiarization with isokinetic exercise, subjects performed 2 sets of four maximal repetitions at 60°·s⁻¹ with 1-min rest between sets (27). The familiarization session was performed between 48 and 72 hr before the first test session. However, to exclude any learning or fatigue effects, peak torque had to be within a 5% difference between the familiarization session and the first set of the experimental session. In case of a difference greater than 5%, the experimental session was repeated 72 hr later.

**Test Sessions**

The two test sessions were counterbalanced and conducted at the same facility and at the same time for each subject. Subjects performed three sets of 10 concentric knee extensions at 60°·s⁻¹. After a minimum of 10 min they performed three sets of 10 repetitions at 180°·s⁻¹. The tests were performed on a Biodex system 3 Isokinetic Dynamometer (Biodex Medical, Inc., Shirley, NY). Calibration of the dynamometer was performed according to the manufacturer’s specifications before every testing session. Subjects sat upright with the axis of rotation of the dynamometer oriented with the lateral femoral condyle of the right knee. Belts were used to secure the thigh, pelvis, and trunk to prevent additional body movement. The chair and dynamometer settings were recorded to ensure the same positioning for all subsequent test sessions. The flexor torque produced by the relaxed leg segment was used for gravity correction. Subjects were instructed to fully extend and flex their knee and to work maximally during each set. Verbal encouragement was given throughout the testing session. After each set, subjects were required to take 60 or 120 s of rest before beginning the next set. The knee strap was released during each rest period to ensure unrestricted blood flow to the quadriceps. The procedures were administered to all subjects by the same investigator (4).

**Blood Lactate**

For blood lactate (BLa) measurement, a 25 mL blood sample was collected from the earlobe at the end of each of the 3 sets for each RI at 60°·s⁻¹. BLa concentration was electroenzimatically determined (2700 YSI, Yellow Springs Instruments, OH). The YSI 2700 was calibrated and checked against standard solutions (YSI 2777). Blood lactate concentrations in capillary samples obtained from the earlobe or from the fingertip are used indistinctly. Since our laboratory has been using the earlobe in all studies, this method was used to standardize our procedures and results.
While puncture the earlobe appears to be more painful, no major complaining was reported from the children in this study.

**Statistical Analyses**

The possible effects of velocity, age, RI and sets on PT were tested by a 4-way mixed factor ANOVA \[\text{age (child or adolescent) x rest interval (60 or 120 s) x sets (1st, 2nd, 3rd) x velocity (60°·s^{-1} or 180°·s^{-1})}\] followed by examinations of any interactions and a LSD post hoc procedure for any main effects. BLa concentration was tested by a 3-way mixed factor ANOVA \[\text{age (child or adolescent) x rest interval (60 or 120 s) x time (pre and posttest)}\]. The probability level of statistical significance was set at \(p < .05\). All calculations were performed using SPSS (version 17.0). Descriptive statistics were expressed as means (± SD).

**Results**

The ANOVA for PT revealed a significant four way interaction of rest by sets by velocity by group. Thus, we ran one three way ANOVA for each age group. There was a significant three way interaction of rest by sets by velocity for adolescents but no significant three way interaction for children. In addition, there was no interaction of rest by sets, rest by velocity or sets by velocity, as well as no significant main effect for rest for children. However, children showed significant main effects for sets and speed. There were no significant differences \((p > .05)\) in PT between sets 2 and 3, but set one was significantly \((p < .05)\) greater than sets 2 and 3. In addition, PT at 60°·s^{-1} was significantly \((p < .05)\) greater than 180°·s^{-1} (Figures 1 and 2).

![Figure 1](image_url) — Mean peak torque (PT) at 60°·s^{-1} for both age-groups. * \(p < .05\) less than 1st set; ‡ \(p < .05\) less than 2nd set; † \(p < .05\) greater than 1min.
The signiﬁcant three way interaction for the adolescent group was followed up by one two way ANOVA (sets x rest) for each velocity (60°·s⁻¹ and 180°·s⁻¹). There was a signiﬁcant interaction for both velocities. Thus, we ran four one way ANOVAs (sets) for each rest time. Results revealed that at 60°·s⁻¹, set one was signiﬁcantly greater than sets 2 and 3, and set 2 was signiﬁcantly greater than set 3 for both rest intervals. At 180°·s⁻¹, set 1 was also signiﬁcantly greater than sets 2 and 3. Set 2 was also signiﬁcantly (p < .05) greater than set 3 (Figures 1 and 2).

The ANOVA for BLa revealed a signiﬁcant three way interaction of rest by time by group. Thus, we ran one two way ANOVA for each age group. There was a signiﬁcant two way interaction of rest by time for adolescents but no signiﬁcant two way interaction for children. In addition, there was no signiﬁcant main effect for rest for children. However, children had a signiﬁcant main effect for time. Children’s BLa was signiﬁcantly (p < .05) greater after the three sets for both rest intervals. Table 1 presents the results of BLa concentrations for both age-groups and both RIs (60 and 120 s) at 60°·s⁻¹.

The signiﬁcant two way interaction for the adolescent group was followed up by two one way ANOVA for each rest interval (60 and 120 s). The results revealed that after three sets at 60°·s⁻¹ BLa was signiﬁcantly (p < .05) greater than baseline for both RIs (Table 1).

Discussion

The purpose of this study was to compare the effect of RI on neuromuscular and metabolic responses between sets of resistance exercise in children and adolescent. The results indicates that children recover faster than adolescent between sets of
a knee extensor exercise at 60°·s⁻¹. However, it appears that at higher contraction velocities (180°·s⁻¹) the differences between boys and teens are diminished. In addition, adolescent experienced a larger increase in blood La concentrations than children on both RIs.

Researchers have been using the isokinetics dynamometers to assess neuromuscular function in children and adolescent since 1970s (15,19,25). However, studies on reference values for children and adolescents are more recent. Wiggin et al. (40) measured the peak torque of 3587 children from 6 to 13 years old at 60°·s⁻¹. They reported an average PT of 80.0 N.m for the children between 10 and 11 years old. These values are similar to the current study (79.5 N.m). Others studies reported values of PT for children similar to the current study. Holm et al. (18), in a longitudinal study, reported a PT of 85.0 N.m for children with a mean age of 11.6 years old. Kotzamanidou et al. (22) also found a PT of 80.1 N.m for children with 10.5 years, and Paraschos et al. (26) reported similar values (85.0 N.m) for children with similar mean age (10.5 years). Regarding to PT in adolescent, Holm et al. (18) reported 202.8 N.m for adolescent with 16.0 years old, and Gerodimos et al. (14) found a PT of 201.5 Nm for adolescent with a mean age of 15.6 years old. These results are also in agreement with the current study (214.6 Nm).

With the purpose to compare muscle performance and muscle recovery in children, Hebestreit et al. (17) reported that children between 8–12 years old were able to recover 100% of the Wingate peak power after 2 min of RI. The adults however needed 10 min to fully recover peak power. By the same token, Lazaar et al. (24), using multiples 10s running sprints with 30s RI, reported a drop in running distance of 20% in young adults and only 12% in children. Ratel et al. (33), also using 30s RI, reported that boys were able to maintain initial peak power but the adults presented a decrease of 28.5% of the initial values. In another study, Ratel et al. (34) reported that children decreased only 14% in performance during repeated bouts of 10s cycle ergometer with 15s RI, whereas the adults decreased 40%.

The isokinetic exercise was also used to compare the age-specific response on fatigue and muscle recovery. Kotzamanidou et al. (22) using a fatigue test of 25 isokinetic repetitions at 60°/s, compared the effect of 1, 2 and 3 min RI on pre-adolescent and adults male. They reported a recovery of 89.1% of the initial PT values for the children and a 69.4% for the adults. Similarly, Zafeiridis et al. (41) also examined the effects of age on recovery of PT of knee extensors during high intensity intermittent 30s and 60s exercise in 19 boys and 17 teens. The 30s high intensity exercise involved 4 sets of 18 maximal knee extensions reps (1min rest

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<td>[BLa] (mM)</td>
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<td>IR</td>
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<td>1.04 ± 0.23</td>
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<td>2min</td>
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* p < .05 greater than baseline; ‡ p < .05 greater than children.
between sets), and the 60s comprised of 2 sets of 34 reps (2 min rest) at 120°·s⁻¹. In the high intensity 60s protocol, the percent recovery for PT after the first set was higher in boys compared with teens in all sets. In the 30s protocol, the percent recovery of PT was higher in boys compared with teens in the last two sets. These results are in agreement to the current study. In addition, similar to the current study, BLa increase was most pronounced in teens and less pronounced in children. Thus, the authors suggested a strong relationship between energy production and anaerobic capacity and found that the differences between the contributions of anaerobic and aerobic pathways for energy production may explain in part the process of fatigue in children and adolescents. In accordance with these reports, it is conceivable to suggest that during high intensity intermittent protocols in the current study, boys relied less on anaerobic glycolysis for energy production, and thus recovered at a more rapid rate and had greater ability for torque production in subsequent sets. In addition, Paraschos et al. (26) compared adults with preadolescents using 25 repetitions at 60°·s⁻¹ in the isokinetic dynamometer. The results showed a decrease at the end of the test of 25.7% for boys and 36.1% for adults. Thus, the three aforementioned studies are consistent with the results of the current study, which demonstrated a better ability of children to recover muscle performance when compared with teenagers.

Dipla et al. (8) also evaluated the age-related muscle recovery on a four sets 1 min RI isokinetic protocol. The authors reported a significant reduction of the PT between the first and fourth sets for adults and teenagers but not for children. Therefore, the authors inferred that the differences between intramuscular mechanisms and fiber types help explain the lower fatigue in children. They concluded that fatigue resistance decreases gradually from childhood to maturation. These results are in accordance with the current study since, with the RI of 1 min, the children showed no significant reduction in the PT during the three sets.

With the purpose to assess the resistance training performance to various RI lengths on the bench press exercise, Faigenbaum et al. (10) compared the effects of three sets with a 10 repetition maximum load on 1, 2, and 3 min RI between sets of boys (n = 12; age 11.3 yr), teens (n = 13; age 13.6 yr), and men (n = 17; age 21.4 yr). They found, significant differences in lifting performance between age groups within each RI for selected sets with boys and teens performing significantly more total repetitions than adults following protocols with 1, 2, and 3 min RIs. Thus, the authors concluded that boys and teens have a better recovery performance than adults in intermittent exercise of moderate intensity. However, different than the current study, they found no significant in performance between boys and teens. This lack of differences may be due to differences in exercise mode and due to the fact that Faigenbaum et al. (10) did not control contraction velocity, thus the working rest ratio may have been different between groups. In addition, Faigenbaum et al. (10) reported significant age-related differences in relative strength between boys (55.7%), teens (68.9%), and adults (124.3%). It appears that the adults can produce twice as much force than boys and teens, and the teens were only 13% strong than the boys. Studies have shown that greater force production is correlated with greater fatigue (10,31). One explanation for this is probably due to stronger individuals experiencing greater intramuscular pressures (37), blood flow occlusion, accumulation of metabolites, impairment of oxygen delivery to the muscle, and an earlier onset of task failure during a sustained contraction (21,28). Furthermore, a
study that directly measured oxygenation reported that muscle oxygenation during a muscle strength task depends on relative rather than the absolute torque (6).

In the current study, adolescent reported larger increases in \( [\text{BLa}] \) concentrations than children on both RIs. Initial studies by Zanconato et al. (42) and Gaul et al. (13) reported lower \( [\text{BLa}] \) concentrations in children when comparing to adults after performing high intensity anaerobic exercise. Ratel et al. (33), using a series of intervals training with cycle ergometers, and Lazzaar et al. (24) using 10s running sprints and 30s RI, also found significant differences among children, adolescents and adults in \( [\text{BLa}] \) concentration. Zafeiridis et al. (41) also reported a lower concentration of Lactate (6.0 mmol/L) in children than in adolescents (8.5 mmol/L) after intermittent high intensity Isokinetic exercises. The differences in lactate concentrations between the Zafeiridis’s study and the current study (~2.5 mmol/L for children and ~6.0 mmol/L for teens) might be explained by the contrasts between protocols. As mention before, Zafeiridis et al. (41) protocol used a greater number of sets and repetitions than the current study. Recently, Dipla et al. (8) also reported significant lower lactate production in children when compared with adolescent. These results are in agreement to the current study.

Eriksson et al. (9) were the first authors to suggest that glycolytic metabolism is less developed in children than in adults. In addition, Eriksson et al. (9) reported a lower concentration of phosphofructokinase enzyme. Other studies have also examined the enzymatic activity in the anaerobic pathway (lactate dehydrogenase, aldolase and pyruvatekinase) and found lower concentrations in children than in adults (2,20). The notion that children have a faster recovery than adults after performing an intense physical exercise seems to be well accepted by exercise specialists. Ratel et al. (35), and Falk and Dotan (12) reported that the metabolic effects for children’s faster recovery from high-intensity exercise are: 1) faster return of acid-base balances, 2) lower peak \([\text{BLa}]\) and \([\text{H}^+]\), 3) faster \( \text{CrP} \) replenishment, 4) lower glycolytic enzyme activity, and 5) lower energy-substrate levels.

Besides these effects, a recent study of Ratel et al. (36), comparing the muscular oxidative capacity by means of 31P-MRS, between children and adults, found that the results reflected a large mitochondrial oxidative capacity in children. In addition, using 31P-MRS, Taylor et al. (38) demonstrated faster intramuscular \( \text{CrP} \) resynthesis and recovery half-times, after graded exercise of the calf muscles in children compared with adults. The faster \( \text{CrP} \) resynthesis has been attributed to children’s greater reliance on oxidative metabolism and lower dependence on glycolytic metabolism. Thus, they concluded that a high capacity for regeneration of ATP, through the aerobic system in children, could be an important factor for improved fatigue resistance in children on high intensity intermittent exercises.

In conclusion, adolescents appear to need the longer rest interval for this specific training protocol. A 1:2 and 1:4 work-to-rest ratio is sufficient to promote full muscle strength recovery between isokinetic strength exercise sets for the children group. However, at higher work-to-rest ratio (1:6 and 1:12) the differences between groups appear are reduced. In addition, as reported by our \( [\text{BLa}] \) results, children’s advantage may lies in the shorter delay between the onset of exercise or its termination and the peaking of metabolites in the blood, allowing the recovery process to commence earlier. Future studies should examine the effect of training with different work-to-rest ratios on muscle function in children and adolescent. Furthermore, is very difficult to control contraction velocity and range of motion
in children during resistance training. Thus, to better control these variables we used the isokinetic dynamometer. However, this is an external validity limitation in the current study. As a result, we also suggest future controlled studies using isoinertial equipment.

References