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Maximal Strength Testing in Healthy Children

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ABSTRACT

Strength training has become an accepted method of conditioning in children. However, there is concern among some observers that maximal strength testing may be inappropriate or potentially injurious to children. The purpose of this study was to evaluate the safety and efficacy of 1 repetition maximum (1RM) strength testing in healthy children. Thirty-two girls and 64 boys between 6.2 and 12.3 years of age (mean age 9.3 ± 1.6 years) volunteered to participate in this study. All subjects were screened for medical conditions that could worsen during maximal strength testing. Under close supervision by qualified professionals, each subject performed a 1RM test on 1 upper-body (standing chest press or seated chest press) and 1 lower-body (leg press or leg extension) exercise using child-size weight training machines. No injuries occurred during the study period, and the testing protocol was well tolerated by the subjects. No gender differences were found for any upper- or lower-body strength test. These findings demonstrate that healthy children can safely perform 1RM strength tests, provided that appropriate procedures are followed.

Key Words: resistance training, strength training, repetition maximum, preadolescents

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Introduction

During the last decade, strength training has proven to be a safe and effective method of conditioning in children, provided that appropriate exercise guidelines are followed. Reports indicate that regular participation in a youth strength-training program may increase muscle strength and local muscular endurance (23), enhance bone mineral density (20), improve body composition (30), and reduce the risk of injuries in sports and recreational activities (28). A growing number of boys and girls seem to be participating in strength-training activities in physical education classes and after school programs, and the qualified acceptance of youth strength training by medical and fitness organizations is becoming universal (1–3, 9).

Current strength-training recommendations for children include the performance of 1–3 sets of 6–15 repetitions on a variety of single- and multi-joint exercises (9). However, maximal strength testing in children remains controversial (7, 17). Some observers believe that 1 repetition maximum (1RM) testing (the maximal amount of weight that can be lifted at one time through a subject's complete range of motion) is inappropriate for children, and others are concerned that this method of testing may cause structural damage to the developing musculoskeletal system of young weight trainers (18, 29). A few retrospective case reports have noted damage to the epiphysis, or growth cartilage, of adolescents who are strength trained with heavy weights (6, 14, 15). However, most of these injuries were due to an improper lifting technique or lack of qualified supervision.

Growth plate fractures have not been reported in any prospective youth strength-training study that used maximal strength testing (e.g., 1RM testing methods on the leg press, chest press, or arm curl exercises) to evaluate training-induced changes in children (11, 22, 23). Yet some coaches, teachers, and health care providers continue to suggest that children should avoid heavy strength training or single maximal attempts (1, 5, 18). Attitudes associated with strength-testing children were highlighted in a recent National Strength and Conditioning Association (NSCA) internet survey, which found that 2,043 of 2,311 responders (88%) believe that 1RM strength testing is inappropriate for children (21). This issue needs further study and evaluation because most of the forces that children are exposed to in sports and recreational activities are likely to be greater in both exposure time and magnitude compared with competently supervised and properly performed maximal strength tests.

Unlike maximal graded exercise testing (25), no prospective trial has evaluated the safety and efficacy of maximal strength testing in children under 13 years of age. Although previous studies have explored the safety of maximal strength testing in cardiac patients (10), pulmonary patients (16), healthy adults (13), and elderly subjects (27), more specific information on

1RM testing in children would be useful for physical educators, youth coaches, and health care providers. Therefore, the purpose of this study was to evaluate the safety of 1RM testing in children and to assess its practical application as a testing tool in this age group. Machine (plate loaded) exercises were used in this study because the subjects had no previous experience in strength training and weight machine exercises are easier to perform than free-weight exercises. In this study, we hypothesized that 1RM strength testing in children could be a safe and worthwhile procedure, provided that testing occurs under controlled conditions and supervision by qualified professionals.

Methods

Experimental Approach to the Problem

In this study, we addressed the safety and efficacy of 1RM testing in healthy children. A group of children who were screened for any medical or orthopedic conditions that would limit their participation performed 1 upper-body and 1 lower-body maximal strength tests under close supervision. This approach allowed us to individually assess 1RM performance and carefully monitor the response of each subject to the testing protocol.

Subjects

Sixty-four boys and 32 girls between 6.2 and 12.3 years of age (mean age 9.3 ± 1.6 years) volunteered to participate in this study. Subjects were recruited from a community-based fitness center. No subject had any previous experience in strength training or strength testing. Both the children and their parents were informed about the objectives and scope of this project and completed a 1-page health history and physical activity questionnaire. The methods and procedures used in this study were approved by the Institutional Review Board for use of human subjects at the University of Massachusetts Boston, and all parents and children provided written informed consent before participation. The exclusionary criteria used were (a) children with a chronic pediatric disease, (b) children with an orthopedic limitation, and (c) children older than 13 years of age. One boy who had a preexisting lower-extremity orthopedic concern did not perform 1RM testing on the lower-body exercise but did perform upper-body testing. All volunteers were accepted for participation. Descriptive characteristics of the subjects are presented by gender in Table 1.

Table 1. Descriptive data by gender.*

	Girls (N = 32)	Boys (N = 64)	p
Age (y)	9.7 ± 1.7	9.0 ± 1.6	0.06
Height (cm)	140.9 ± 11.6	135.7 ± 9.8	0.02
Weight (kg)	40.8 ± 13.1	37.1 ± 10.6	0.14

* Values are expressed as mean ± *SD*.

Testing Procedures

All subjects participated in an introductory training session before testing procedures. During this time, they were taught the proper technique (i.e., controlled movements and proper breathing) on each testing exercise, and any questions they had were answered. A warm-up session of about 10 minutes of low- to moderate-intensity aerobic exercise and stretching preceded all tests. All measurements for testing were performed by the same test administrators and in the same position using child-size dynamic constant external resistance equipment (leg press and seated chest press, Fit Systems, Inc., Sugar Land, TX; leg extension and standing chest press, Schnell Equipment, Peutenhausen, Germany). The plate-loaded weight machines used in this study are similar in design to the traditional adult-size weight machines; however, they are scaled down to fit the smaller body frame of a child. This type of strength-training equipment is currently used in some physical education classes and recreational programs. After the testing procedures, subjects performed about 5 minutes of stretching exercises.

Performance Strength

Each subject's 1RM strength was determined on 1 upper-body and 1 lower-body exercise depending on the availability of the equipment at the testing center on the testing date. Subjects performed a 1RM on either the standing chest press (n = 41) and leg extension (n = 41) or on the seated chest press (n = 55) and leg press (n = 54). The 1RM was recorded as the maximum resistance that could be lifted throughout the full range of motion (determined in the unweighted position) using good form once. Before attempting a 1RM, subjects performed 6 repetitions with a relatively light load, then 3 repetitions with a heavier load, and finally a series of single repetitions with increasing loads. If the weight was lifted with the proper form, the weight was increased by approximately 0.5–2.3 kg, and the subject attempted another repetition. The increments in weight were dependent on the effort required for the lift and became progressively smaller as the subject approached the 1RM. On average, the upper- and lower-body 1RM measures were determined within 7 and 11 trials, respectively. Failure was defined as a lift falling short of the full range of motion on at least 2 attempts spaced at least 2 minutes apart.

Throughout all testing procedures, a NSCA-certified Strength and Conditioning Specialist supervised the tests, and an instructor to subject ratio of 1:1 was maintained. Each test administrator had previous experience working with boys and girls in the weight room and understood the physical and psychological

Table 2. One repetition maximum results by gender.*

	Girls	Boys
Leg press (kg)	60.2 ± 19.8	59.2 ± 19.3
Leg extension (kg)	19.3 ± 7.3	17.8 ± 7.9
Standing chest press (kg)	24.0 ± 5.7	24.6 ± 7.7
Seated chest press (kg)	22.0 ± 6.5	20.5 ± 5.9

* Values are expressed as mean ± *SD*.

uniqueness of children. Communication between the subject and the test administrator was positive, and questions such as ''How do you feel?'' ''Is the weight light, medium or heavy?'' and ''Can you lift more?'' were asked to aid in the progression of the 1RM trials. The test administrators encouraged boys and girls to try their best and regularly reminded all subjects to maintain proper exercise technique.

All testing took place after school or on weekends in a YMCA youth fitness center, and subjects performed both strength tests on the same day. A maximum of 4 children were allowed in the youth fitness center during the testing sessions, which took about 60 minutes to complete. Uniform verbal encouragement was offered to all subjects, and the testing order was randomized. Approximately 2–4 days after the strength tests, the subjects returned to the testing center and were individually questioned by the test administrators (doctoral-level exercise physiologists) for the occurrence of an injury and complaints of muscle soreness. For this study, muscle soreness was considered to be severe if a subject had to alter or stop his or her involvement in any physical activity.

Statistical Analyses

Unpaired *t*-tests were used to compare gender differences in descriptive variables and 1RM results. Statistical significance was set at $p \leq 0.05$ and analyses were conducted using the statistical package for social sciences (SPSS, Inc., Chicago, IL). All values are presented as mean ± *SD*.

Results

All the subjects completed the testing protocol according to the aforementioned methodology. There were no significant differences in age or weight between the girls and boys, but girls were significantly taller than the boys (Table 1). No injuries occurred throughout the study period, and the testing procedures were well tolerated by the subjects. No complaints of severe muscle soreness were reported. No significant differences were found between boys and girls on any upper- or lower-body 1RM test. The 1RM data for the leg press, leg extension, standing chest press, and seated chest press are presented by gender in Table 2. In this study, 56% of the subjects participated regularly (at least twice per week) in organized sports programs (principally soccer and swimming).

Discussion

To our knowledge, no other study has evaluated the safety and efficacy of maximal strength testing in boys and girls under 13 years of age. Results from this investigation indicate no abnormal responses to or injury from 1RM testing, and comments from the subjects and their parents suggest that children enjoyed participating in this study. Further, no significant differences were observed between boys and girls on any strength measure. These findings suggest that the maximal force production capabilities of healthy children can be safely evaluated by 1RM testing, provided that appropriate testing guidelines are followed. However, it must be underscored that all children in this study were screened before participation, and all procedures were closely supervised by qualified test administrators. The findings from this study may not be applicable to children with disease, adolescents, or to cases where strength tests are administered by inexperienced teachers, coaches, or health care providers.

A common concern associated with maximal strength testing in children addresses the potential for injury to the epiphyseal plate or growth cartilage. Although this type of injury has been reported in adolescents who attempted to lift heavy loads in unsupervised settings (6, 14, 15), epiphyseal plate fractures have not been reported in any prospective youth strength-training study that used 1RM strength-testing procedures (11, 22, 23). Although children are susceptible to this type of injury, if qualified instructors teach children how to perform each exercise correctly using an appropriate load, it seems that the risk of an epiphyseal plate fracture is minimal. Interestingly, it has been suggested that the risk of injury to the epiphyseal plate in children is less than in adolescents because the epiphyseal plates of younger children are stronger and more resistant to shearing type forces (19).

In this study, children performed a series of sets with increasing loads until their 1RM was determined. Because normative data on the maximal strength capabilities of children have not yet been established, the weight was increased conservatively until the 1RM was determined. Although strength-testing guidelines for adults suggest that the 1RM should be determined within 5 testing sets (4), observations of this study suggest that additional sets (e.g., 7–11) may be needed to accurately determine the 1RM in children who have no experience in strength-testing procedures. Because untrained children and adults have more difficulty in activating their muscles (26), the performance of additional testing sets (with adequate rest between sets) may aid in the recruitment and coordination of the involved muscle groups. Anecdotal observations of our study suggest that a child's perception of a given weight (i.e., light, medium, or heavy) may waver during the first 3–5 testing sets. That is, as the weight load increased, some children perceived the load to be ''lighter'' or ''easier'' than the previous set. Further, 68% of the subjects who could not lift a given weight during their first attempt at a 1RM trial, successfully completed the lift on their second attempt. Although speculative, a gradual increase in the weight used for testing combined with additional testing sets (and a second attempt if necessary) may aid in the accuracy of strength testing in children. Providing children with an opportunity to practice proper exercise technique on several occasions before the testing date may also improve 1RM performance.

In addition to their use in the clinical assessment of children with musculoskeletal disorders, the results of 1RM testing can be used to track children's progress, develop personalized fitness programs, provide motivation, and assess the effectiveness of a strength-training program. Strength tests can also be used to identify and treat correctable risk factors, such as muscle imbalances and poor lower-body strength. Test-retest reliabilities from our laboratory for 1RM testing in children vary from 0.93 to 0.98 depending on the choice of exercise (12). However, when properly administered, 1RM strength-testing procedures are labor intensive and time consuming. Maximal strength testing can be used by researchers to evaluate training-induced changes in muscular strength in children, although the use of 1RM testing in physical education classes and youth sport programs may be limited. Additional studies are needed to identify in children the simple field-based measures that relate to maximum muscular strength.

This study attempted to determine whether 1RM strength testing is a safe procedure for children. Our findings are supportive of smaller studies that used maximal strength testing in children without any apparent adverse consequences (11, 22, 23). However, there are several aspects of the safety issue that cannot be addressed in our study. No conclusions can be drawn regarding the acute effects of maximal strength testing on subclinical measures of muscle damage or the chronic effects of maximal strength testing on bone tissue or bone growth. Further, because weight machines were used for all tests in this study, the safety and efficacy of 1RM testing in children using other modes of testing (e.g., dumbbells and barbells) remain uncertain. Also, because we did not assess the biologic maturation of the subjects, it is possible that older subjects may have entered their pubertal years.

Practical Applications

The present study serves to document the safety and efficacy of 1RM strength testing in healthy children. Because of the growing popularity of youth strength training and the potential health benefits associated with this method of conditioning (8), 1RM strength tests can be used by qualified professionals to evaluate the effectiveness of a youth conditioning program, assess strengths and weaknesses, provide motivation, and teach children the fundamental concepts of physical fitness, which should include strength training. Conversely, unsupervised and poorly performed maximal strength tests are not recommended under any circumstances because of the potential for injury (24).

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