Effects and Mechanisms of Strength Training in Children

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Key words
- resistance training
- weight training
- youth
- muscle mass
- peak torque
- jumping height

Abstract
It has been demonstrated that strength training can be organized in children in a safe and effective way. However, there is limited data regarding its impact on muscle hypertrophy. This study investigated the effects of a high-intensity strength training (HIS) on knee extensor/ flexor strength, countermovement (CMJ) jumping height, postural control, soft lean mass and muscle cross-sectional area (CSA) of the dominant leg in prepubertal children. Thirty-two children participated in this study and were assigned to an intervention (INT; n=17) or a control class (n=15). The INT participated in 10 weeks of weight-machine based HIS integrated in physical education. Pre/post tests included the measurements of peak torque of the knee extensors/ flexors at 60 and 180°/s, CMJ jumping height, postural sway, soft lean mass of the leg by bioelectrical impedance analysis, and CSA (m. quadriceps) by magnetic resonance imaging. HIS resulted in significant increases in knee extensor/ flexor peak torque (60°/s and 180°/s). HIS did not produce significant changes in CMJ jumping height, postural sway, soft lean mass, and CSA. Although HIS was effective at increasing peak torque of the knee extensors/ flexors in children, it was unable to affect muscle size. It appears that neural factors rather than muscle hypertrophy account for the observed strength gains in children.

Introduction
Over the past 25–35 years, secular declines in motor fitness levels (e.g., strength, balance) were noticed in children and adolescents [26] that appear to be related to increased injury rates [18,38,41]. Thus, adequate intervention programs have to be administered which have the potential to enhance motor fitness already at an early age. Schools provide an excellent opportunity for fitness promotion as they access a large population of children across broad ethnic and socioeconomic strata [31]. In addition, due to governmental promotion, a tendency towards all-day schools can be noticed in many European countries. As a consequence, children spend more time of their waking hours in school during the school year and have less time to attend organized sports (e.g., sports clubs) in after school hours, as practiced in the past. There is increasing evidence in the literature indicating that strength training is an effective tool for the promotion of fitness and health in prepubertal children [1,7,9]. In fact, Falk and Tenenbaum [12] conducted a meta-analysis and reported training-induced strength increases of 13–30% (effect size (ES)=0.57) in preadolescent children following strength training programs of 8–20 weeks. Of note, one study even documented a 74% increase in strength of lower extremity muscles following 8 weeks of training in children between the ages of 8–12 years [10]. In another meta-analysis on strength training in children and adolescents, Payne et al. [33] reported higher ES for the younger (ES=0.75) than for the older group (ES=0.69) indicating that children’s adaptive potential to strength training may even be larger than that of adolescents. Notably, the effects of strength training in children are not restricted to strength improvements. In fact, resistance exercise has the potential to strengthen specific muscles of the lower extremities that result in increased joint stability and thus decreased postural sway [20,36]. Further, some studies demonstrated that training-induced strength gains in children resulted in improved performance in selected motor fitness skills (e.g., long jump) [11] as well as in reduced sport injury

Bibliography
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rates (e.g., soccer) [21]. In addition, it was recently shown that strength training has the potential to increase spontaneous physical activity and to decrease waist circumference and percent body fat in children [2,5]. Most important, strength training proved to be safe and feasible in this age group [9]. This was illustrated in a recent study [30] showing that children have a lower risk of sustaining strength training-related joint sprains and muscle strains than adults. In fact, it has been demonstrated that the majority of youth strength training injuries are the result of accidents that are potentially preventable with increased supervision and stricter safety guidelines [30].

The question regarding the appropriate dose-response relationship in strength training for children is still open for debate. Recently, Faigenbaum et al. [7] postulated that low intensity/volume and short duration strength training may not be sufficient enough to induce adaptive processes following strength training in children that differentiate from gains due to normal growth and development. Thus, it appears that even in this age group, progressive high-intensity strength training (HIS) may have a large potential to produce marked increases in strength. In adults, strength gains following 3–5 weeks of HIS primarily occur due to neural mechanisms. After this period, increased muscle fibre size is the main contributor to strength improvements [37]. In children, there is still discrepancy in the literature regarding this issue [14,29,35,39]. It was argued that due to a lack of circulating androgens in prepubertal children, training-induced strength increases are primarily caused by neural rather than muscular factors [24,32]. Nevertheless, there are 2 studies which were able to demonstrate enlarged muscle cross-sectional areas (CSA) following 10–12 weeks of isometric strength training for the upper [14] or lower extremities [29] in healthy prepubertal children. However, from a methodological point of view, these studies are limited in terms of sample size [29] and applied testing apparatus for the detection of training-induced changes in muscle size [14]. Therefore, the objectives of this study were to investigate the effects of a standardized HIS on knee extensor/flexor strength, countermovement (CMJ) jumping height, static postural control, soft lean mass and CSA of the quadriceps muscle of the dominant leg. We hypothesized that children in the intervention as compared to the control group would show significant improvements in muscle strength and postural control. Further, based on selected results reported in the literature [14,29] and due to the application of sensitive measuring techniques (i.e., magnetic resonance imaging) in this study as compared to an earlier study [14], increases in soft lean mass and CSA were expected. The intervention was performed during regular physical education classes to ensure compliance and to test the feasibility of integrating such a program in the regular school curriculum.

Materials and Methods

To test our hypothesis, adaptations following HIS were compared in a controlled longitudinal training study. The training period lasted 10 weeks to ensure neuromuscular modifications. Strength and balance improvements were verified by an analysis of isokinetic peak force at different movement velocities, jumping height, and postural sway. In addition, potential training-induced changes in muscle properties were assessed by using bioelectrical impedance and magnetic resonance imaging (MRI). Both gains in force production and balance control developed during regular physical education lessons are of vital importance for activities of daily living, for several sports-related skills, as well as for injury prevention.

Participants

Twenty primary schools in the greater area of Basel, Switzerland were contacted and asked to participate in the study. The first 2 schools that agreed to take part in the study were selected and randomly assigned to either the intervention (INT) or the control school/group (CON). An a priori power analysis [13] with an assumed Type I error of 0.05 and a Type II error rate of 0.10 (90% statistical power) was calculated for our primary outcome measure isokinetic peak torque [35] and revealed that 15 participants per school/group would be sufficient for finding a statistically significant interaction effect. Due to potential dropouts, 17 third-grade children were randomly recruited in each school and stratified for gender. Two subjects from the CON dropped out due to injury and illness which is why a total of 32 subjects participated in this study. Characteristics of the study population are described in Table 1. None had any history of musculoskeletal, neurological or orthopaedic disorder that might have affected their ability to execute resistance training or to perform strength and balance tests. Parents’ and participants’ written informed consent was obtained before the start of the study. None of the children had an athletic background and none had previously participated in systematic resistance and/or balance training. All children performed less than 5 h of sports activities a week (including physical education). The study was approved by the ethics committee of the University of Basel and all experiments were conducted according to the latest revision of the declaration of Helsinki. Our study meets the ethical standards of the journal [17].

Procedures

Training

Before intervention, the regular physical education teacher that supervised the strength training program was thoroughly instructed in strength training methodology and testing by experts in the field. The intervention program was taught by the physical education teacher together with 2 experts on strength training in order to keep the children-to-teacher ratio small (3 teachers vs. 17 children). The INT-group conducted a HIS program based on youth strength training guidelines provided by Faigenbaum et al. [6] that is described in Table 2. Briefly, HIS was organized as a circuit-training with each teacher supervising 3 stages. Participating children always exercised in pairs so that one child trained and the other one provided support (i.e., motivation, spotting). Subjects exercised on weight machines for the lower extremities (CYBEX EAGLE Premier Line). The manufacturer adapted the weight machines (i.e., seats) to make them suitable for the size of the participating children. Training inten-

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<th>Table 1</th>
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<td>Characteristic</td>
<td>INT (n=17)</td>
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<td>age (years)</td>
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<td>body height (cm)</td>
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<td>body mass (kg)</td>
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<td>body mass index (kg/m²)</td>
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<td>Tanner stage (pubic hair development)</td>
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<td>sex (f/m)</td>
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Note: Values are mean ± SD. INT = intervention group; CON = control group

sity was controlled and changed (when necessary) on a fortnightly basis by means of one repetition maximum (1RM) tests. It was previously demonstrated that healthy children can safely perform a 1RM test [8]. In addition, core exercises were included in the conditioning program to particularly train the abdominal and the lumbar muscles. All sessions were documented and supervised by 2 authors of the study. Participants of the CON-group attended their regular physical education lessons (also 2 times a week) during the 10-week intervention period and were primarily taught in different types of ball games and swimming. No specific strength building exercises were performed during their physical education lessons. All subjects were advised not to decrease or increase their daily sport activities between pre and post tests.

Testing
Prior to balance and strength testing, a bioelectrical impedance analysis was conducted to assess soft lean mass of the dominant leg. Further, quadriceps femoris CSA was analyzed using MRI. Thereafter, all subjects underwent a standardized 10 min warm-up consisting of balance, submaximal plyometric, and skipping exercises. Balance and strength tests included (a) measurements of static postural control on a balance platform, (b) the analysis of CMJ jumping height on a force plate, and (c) the assessment of maximal isokinetic peak torque of the knee extensors and flexors on an isokinetic dynamometer. This sequence of measurements was applied for 2 reasons: First, to keep the bioelectrical impedance analysis and the MRI free from prior movement artefacts (i.e., maximal strength tests) and second, to keep the effects of neuromuscular fatigue minimal during balance and strength testing.

Measurement of knee extensor and flexor peak torque
Peak isokinetic torque of the knee extensors/flexors was measured on an isokinetic dynamometer (Con-Trex MJ System®, Dübendorf, Switzerland) at angular velocities of 60°/s and 180°/s. Subjects were comfortably seated on the dynamometer chair, with the hip joint adjusted at about 85° (0° = full extension). The distal shin pad of the dynamometer was attached 2–3 cm proximal to the lateral malleolus by using a strap. To minimize evasive movements of the upper and lower body during testing, straps were applied across the chest, pelvis, and mid-thigh. The alignment between the dynamometer rotational axis and the knee joint rotation axis (lateral femoral epicondyle) was checked at the beginning of each trial. Further, participants were asked to cross their arms in front of their chest. The exact position of each participant was documented and saved so that it was identical in pre and post tests. The children were given standardized verbal encouragement by the investigator based on online visual feedback of the instantaneous dynamometer torque. Testing was performed with the dominant leg. Before the testing started, participants warmed up by doing 3 submaximal isokinetic actions at 60°/s and 180°/s in the isokinetic system to get accustomed to the testing procedure. Thereafter, each subject performed 3 isokinetic knee extension/flexion exercises with maximal voluntary effort at 60°/s in a concentric-concentric mode. After a 5 min rest, another 3 isokinetic knee extension/flexion exercises were performed with maximal voluntary effort at 180°/s in a concentric-concentric mode. For each trial, participants were thoroughly instructed to act as forcefully as possible, to complete the full range of motion, and to avoid forced respiration. The torque signal was sampled at 100 Hz. During offline analysis, the best trial in terms of peak torque under isokinetic conditions at angular velocities of 60°/s and 180°/s was selected and used for further data analyses. Peak torque was defined as the maximal voluntary torque value of the torque-time curve, determined under isokinetic conditions.

Measurement of CMJ jumping height
Participants performed maximal vertical CMJ while standing on a one-dimensional force platform (SPSport®, MLD-Station Evo2, Innsbruck, Austria). The vertical ground reaction force was sampled at 1000 Hz. During the CMJ, subjects stood in an upright position on the force plate and were instructed to begin the jump with a downward movement, which was immediately followed by a concentric upward movement, resulting in a maximal vertical jump. Jumping height was assessed using the impulse-momentum method [23]. Subjects performed 3 CMJs with a resting period of 1 min between jumps. For each of these trials, subjects were asked to jump as high as possible. The best trial in terms of maximal jumping height was taken for further data analysis. This protocol has recently been described in detail elsewhere [15].
Measurement of soft lean mass
Soft lean mass of the dominant leg was assessed by bioelectrical impedance analysis (InBody 720, Biospace, Seoul, Korea). The dominant leg was determined according to the lateral preference inventory [4]. The tactile-electrode impedance uses an alternating current of 250 mA at frequencies of 1, 5, 250, 500, and 1000 kHz to detect resistance of the different body segments. This impedance meter makes use of 8 electrodes. 2 electrodes are in contact with the palm and thumb of each hand and 2 with the anterior and posterior aspects of the sole of each foot. Before testing, participants did not exercise and fasted for at least 3h. During testing, subjects were in upright quiet stance with bare feet on the footplate and held electrodes in both hands. Dominant leg resistance at frequency x (R8-white body) was calculated for the dominant leg based on a recently published formula that was developed in a large group of randomly selected elementary school children [22].

Measurement of muscle cross-sectional area
Testing of m. quadriceps CSA was conducted in a sub-sample of 13 subjects (n = 6 INT; n = 7 CON). The integration of a sub-sample in our study design was necessary because not all parents gave their written informed consent to allow MRI scans of their children. MRI data were obtained with a Philips Intera 1.5 Tesla scanner (Philips Medical Systems, Best, Netherlands). The subjects were placed in supine position with the feet first in the magnet. The images included the dominant leg and were collected using a body coil. Consecutive transversal T1 and T2 weighted images without gap were assessed with 4mm slice thickness from the superior aspect of the hip to knee joint level. Thus, muscle CSA of the thigh was obtained as an outcome measure by outlining the entire quadriceps musculature for every slice obtained. Afterwards quadriceps muscle volume was calculated by adding each outlined region of interest. The examiner of the MRI scans was unaware of either subject group placement (INT vs. CON) or testing condition (pre vs. post).

Measurement of static postural control
Test circumstances (e.g., room illumination, temperature, noise) were in accordance with recommendations for posturographic testing [19]. Static postural control was assessed by a balance platform (GKS 1000®, IMM, Mittweida, Germany). The balance platform consists of 4 sensors measuring displacements of the COP in the medio-lateral and anterior-posterior directions. Under static conditions, the balance platform was firmly fixed on the floor. For experimental testing, children were asked to stand on their dominant leg on the platform with their supported leg in 30° flexion, hands placed on hips and gaze fixed on a figure (coloured snowman) on the nearby wall. Subjects were instructed to remain as stable as possible and to refrain from any voluntary movements during the trials. Prior to testing, children performed 2 practice trials on the balance platform. Thereafter, one test trial was conducted. If participants did not accomplish the whole sampling duration, they were allowed to repeat. Data was acquired for 30s at a sampling rate of 40Hz [19]. Total displacement of the COP was computed (summed displacements in medio-lateral and anterior-posterior directions). This protocol has recently been described in detail elsewhere [15].

Statistical analyses
Data are presented as mean values ± standard deviations (SD). A multivariate analysis of variance (MANOVA) was used to detect differences between study groups in all baseline variables. The effects of HIS on strength and balance parameters were analyzed in separate 2 (Group: INT, CON) × 2 (Test: pre, post) ANOVA with repeated measures on test. Our ANOVA model was corrected for gender. The classification of ES was determined by calculating partial η². The ES is a measure of the effectiveness of a treatment and it helps to determine whether a statistically significant difference is a difference of practical concern. ES-values = 0.10 indicate small, ES = 0.25 medium, and ES = 0.40 large effects [3]. The significance level was set at p < 0.05. All analyses were performed using Statistical Package for Social Sciences (SPSS) version 17.0.

Results
All subjects received treatment or control conditions as allocated. 17 participants completed the HIS program and none reported any training-related injury. The INT showed a high attendance rate at training sessions with 95%. ▼Table 3 describes baseline and post intervention results for all outcome variables. Overall, there were no statistically significant differences in baseline values between the 2 groups.

Knee extensor and flexor peak torque
Intraclass correlation coefficients were calculated for peak torque of the knee extensors at angular velocities of 60°/s (ICC = 0.93) and 180°/s (ICC = 0.99) as well as for knee flexors at 60°/s (ICC = 0.92) and 180°/s (ICC = 0.97). The statistical analysis indicated significant Group × Test interactions for the knee extensors at movement velocities of 60°/s

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<thead>
<tr>
<th>Parameter</th>
<th>INT (n = 17)</th>
<th>CON (n = 15)</th>
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<tbody>
<tr>
<td>Peak torque of the knee extensors at 60°/s (Nm)</td>
<td>40.1 ± 8.6</td>
<td>41.8 ± 10.5</td>
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<tr>
<td>Peak torque of the knee flexors at 60°/s (Nm)</td>
<td>32.8 ± 5.2</td>
<td>34.2 ± 9.5</td>
</tr>
<tr>
<td>Peak torque of the knee extensors at 180°/s (Nm)</td>
<td>33.1 ± 5.4</td>
<td>36.1 ± 8.0</td>
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<tr>
<td>Peak torque of the knee flexors at 180°/s (Nm)</td>
<td>28.7 ± 3.6</td>
<td>32.9 ± 8.9</td>
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<tr>
<td>CMJ jumping height (cm)</td>
<td>21.5 ± 2.6</td>
<td>20.8 ± 4.0</td>
</tr>
<tr>
<td>Total COP displacements (mm)</td>
<td>1799.9 ± 614.4</td>
<td>1893.0 ± 471.2</td>
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<td>Soft lean mass of the leg (kg)</td>
<td>3.2 ± 0.4</td>
<td>3.5 ± 0.8</td>
</tr>
<tr>
<td>M. quadriceps cross-sectional area (mm)</td>
<td>311.9 ± 41.8</td>
<td>295.4 ± 49.7</td>
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</table>

Notes: Values are mean ± SD. INT = intervention group; CON = control group; CMJ = countermovement jump; COP = centre of pressure

The analysis failed to indicate a significant interaction effect for the parameter CMJ jumping height \( (F(1, 62) = 0.25, p = 0.876, \eta^2 = 0.001, ES = 0.03) \) (Fig. 3). In addition, no significant Group × Test interaction was observed for total COP displacements during one-legged quiet stance \( (F(1, 62) = 2.37, p = 0.135, \eta^2 = 0.078, ES = 0.29) \) (Fig. 3).

Soft lean mass and muscle cross-sectional area
The intraclass correlation coefficient (ICC) was calculated for soft lean mass (ICC = 0.99) and muscle cross-sectional area (ICC = 0.98) of the dominant leg.

Group × Test interactions did not reach the level of significance for the parameters soft lean mass of the dominant leg \( (F(1, 62) = 0.23, p = 0.635, \eta^2 = 0.008, ES = 0.09) \) and CSA of the quadriceps muscle \( (F(1, 62) = 0.21, p = 0.655, \eta^2 = 0.019, ES = 0.14) \) (Fig. 4).

Controlling our statistical analyses for gender did not affect conclusions of the statistical tests.

Discussion
To the authors’ knowledge, this is the first study that investigated the effects of a school-based HIS program in prepubertal children on peak torque of the knee extensors/flexors, jumping height in CMJ, measures of static postural control, and changes in muscle properties of the lower extremities. The main findings...
of this study were that (1) peak torque of the knee extensors and flexors were significantly improved at movement velocities of 60°/s and 180°/s following 10 weeks of HIS; (2) strength gains in knee extensors and flexors did not result in significant improvements in CMJ jumping height; (3) measures of static postural control were not significantly influenced by HIS; (4) HIS did not induce significant changes in soft lean mass as well as in muscle CSA (m. quadriceps) of the dominant leg. The present results are in accordance with literature regarding the effects of strength training on peak torque of the knee extensors/flexors. Following 9 weeks of strength training, Pfeiffer et al. [34] found increases in peak torque of the knee extensors/flexors at movement velocities of 30°/s and 120°/s in Tanner stage 1 boys. In addition, Weltman et al. [40] observed increases in peak torque of the knee extensors/flexors at movement velocities of 30°/s and 90°/s following 14 weeks of strength training in boys aged 6–11 years (Tanner stage 1). Notably, our subjects exercised their knee extensors/flexors on weight-machines at moderate contraction velocity and under concentric/eccentric mode. Despite this training modality, improvements in peak torque of the knee extensors/flexors were observed under isokinetic conditions at a high (180°/s) movement velocity. Therefore, it seems plausible to argue that under single-joint conditions transfer in strength gains were possible between training and testing modalities. This is in accordance with the results of Pfeiffer et al. [34]. In the present study, increases in strength due to HIS were restricted to the knee extensors/flexors only and did not result in improved CMJ jumping height even though the leg extensors were exercised on the leg-press. This may indicate that training-induced adaptations were exercise specific. More specifically, the successful performance of a CMJ requires exercisers to keep their centre of mass at all times over a relatively small base of support (i.e., feet), whereas the performance of a seated leg-press exercise does not afford this coordinative aspect. Of note, Granacher et al. [16] were recently able to show that 8 weeks of ballistic strength training implemented in regular physical education lessons significantly improved CMJ jumping height in a cohort of adolescents. Additionally, Weltman et al. [40] observed an increase in jumping height following 14 weeks of hydraulic strength training in prepubertal boys. In contrast to the present study, those studies included back squat [16] or jump squat [40] exercises in their strength training programs. Thus, in accordance with the principle of training specificity it is argued that squat exercises could have been responsible for the training-induced improvements in jumping height. Given these results, it is suggested that youth strength training programs should involve a large variety of exercises including some kind of plyometrics to enable transfer from training-induced strength gains to sports-related skills.

Ten weeks of HIS did not significantly influence static balance performance during one-legged stance. Our finding is in accordance with the results of a study conducted by Granacher et al. [16] who did not observe a significant impact of ballistic strength training on measures of static and dynamic postural control in high-school students. The authors argued that neural adaptive processes following ballistic strength training are task-specific and therefore not transferable to balance performance. From an injury-preventive point of view, our results suggest that specific and possibly dynamic balance exercises should be included in a conditioning program if the goal is to improve postural control and to ultimately reduce the rate of sustaining injuries. In support of our idea, Kibele and Behm [20] recommended weight-machine based strength training on unstable devices as an alternative to improve strength, balance, and functional performance. It was demonstrated that unstable strength training did provide an advantage in selected functional performance tasks over traditional strength training. In addition, Mandelbaum et al. [25] were able to show that particularly conditioning programs including resistance and balance exercises are effective in reducing sports-related injuries in adolescent athletes. However, further studies are needed to investigate this issue in children. In the present study, no significant changes were detected in soft lean mass and quadriceps CSA of the dominant leg. There is only limited data available in the literature regarding the effects of strength training on muscle size in prepubertal children. In an early study, Vrijens [39] found no significant changes in arm and thigh girth as well as in muscle CSA determined by soft tissue x-ray in prepubescent boys after 8 weeks of strength training. Ramsay et al. [35] investigated the impact of a 20 week progressive HIS program on peak torque and muscle CSA (measured by computerized tomography) of the knee extensors in a cohort of 9–11 year-old boys (Tanner stage 1). After training, peak torque of the knee extensors at angular velocities of 30, 60, 120, and 180°/s was significantly enhanced across all movement velocities. The statistical analysis of muscle CSA revealed a main effect of time for knee extensor CSA which is indicative of growth due to maturation. However, no significant Group × Test interaction was found which suggests that strength gains were independent of changes in muscle CSA. In contrast to these findings, Morsch and Stoboy [29] reported significant concomitant increases in isometric leg extension and knee extensor CSA determined by nuclear MRI in 2 trained twins following 10 weeks of isometric strength training. Fukunaga et al. [14] used the ultrasound technique to demonstrate increases in muscle CSA of the upper arm among prepubertal 1st to 3rd grade boys and girls aged 9–12 years who engaged in isometric strength training for the elbow flexors over 12 weeks. After training, a significant increase in muscle CSA of the upper arm was observed in 3rd grade boys only. Notably, the increment in muscle CSA following training approximated only 50% of that seen in a study with grown-ups [14]. Recently, Mcnee et al. [28] investigated the effects of a 10 week planter flexor strength training on number of unilateral heel raises, functional performance (e.g., walking speed, Timed Up and Go Test), and muscle volume of the planter flexors determined by ultrasound in children with spastic cerebral palsy (mean age 10±3 years). Strength training resulted in a significant increase in number of heel raises as well as in volume of the medial and lateral gastrocnemius. However, no significant changes in measured function (i.e., Timed Up and Go Test) were observed due to training. In another study, Mcguigan et al. [27] examined the effects of 8 weeks of strength training on variables of strength and jumping height as well as on measures of body composition determined by dual-energy X-ray absorptiometry in overweight or obese children between the ages of 7 and 12 years (Tanner stages 1 and 2). Following training, significant increases in the 1RM during a machine squat exercise as well as in CMJ jumping height were observed. In addition, the authors reported a training-induced significant increase in lean body mass. Given the conflicting results in literature regarding the effects of strength training on muscle hypertrophy in prepubertal children together with the small sample size (n=4) in the study of
the longest period during the school year that is not interrupted by school holidays amounts to 10 weeks. Since we wanted to realize this intervention program in a school setting during regular physical education to test its feasibility and because the participating children could not attend training sessions during their school vacation, we had to accept these time restrictions.

Conclusion

In summary, the results of this study illustrate that HIS is a feasible and safe training modality that produces marked increases in peak isokinetic torque of the knee extensors/flexors at 60°/s and 180°/s in healthy prepubertal children. Unfortunately, HIS did not produce significant improvements in CMJ jumping height and static postural control. This may imply that plyometric and balance exercises should be included in a conditioning program for children to enable (a) transfer from training-induced strength gains to sports-related skills, and (b) injury-preventive effects. Since we were not able to detect significant changes in soft lean mass and muscle CSA of lower extremity muscles following HIS in prepubertal children, it is suggested that the observed strength gains were primarily caused by neural factors with hypertrophy playing a minor role.

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References

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11 Falk B, Mor G. The effects of resistance and martial arts training in 6- to 8-year-old boys. Ped Exerc Sci 1996; 8: 48–56