PEDIATRICS®
OFFICIAL JOURNAL OF THE AMERICAN ACADEMY OF PEDIATRICS

Strength Training and Physical Activity in Boys: a Randomized Trial

Udo Meinhardt, Fabienne Witassek, Renato Petrò, Chris Fritz and Urs Eiholzer

Pediatrics; originally published online November 4, 2013;
DOI: 10.1542/peds.2013-1343

Strength Training and Physical Activity in Boys: a Randomized Trial

AUTHORS: Udo Meinhardt, MD, Fabienne Witassek, MSc, Renato Petrò, BSs, Chris Fritz, BSs, and Urs Eiholzer, MD

PEZZ Center for Pediatric Endocrinology Zurich, Zurich, Switzerland

KEY WORDS

spontaneous physical activity, children, puberty, strength training

ABBREVIATIONS

BA—bone age
FM—fat mass
LBM—lean body mass
PA—physical activity
PAEE—physical activity energy expenditure
PE—physical education
PWS—Prader-Willi syndrome
SDS—standard deviation score

Dr Meinhardt conceptualized and designed the study, designed the data collection instruments, carried out the initial data analyses, and revised the manuscript; Ms Witassek conceptualized and designed the study, analyzed output data, and revised the manuscript; Mr Petrò conceptualized and designed the study, coordinated and supervised data collection, and revised the manuscript; Mrs Fritz conceptualized and designed the study, analyzed data, and revised the manuscript; Dr Eiholzer conceptualized and designed the study, analyzed and interpreted data, and revised the manuscript; and all authors approved the final manuscript as submitted.

This trial has been registered with the New Zealand Clinical Trials Registry (ANZCTR) (identifier ACTRN12613000509763).

www.pediatrics.org/cgi/doi/10.1542/peds.2013-1343

doi:10.1542/peds.2013-1343

Accepted for publication Sep 3, 2013

Address correspondence to Urs Eiholzer, MD, Head of the Center for Pediatric Endocrinology Zurich, Moehrlistrasse 69, CH-8006 Zurich, Switzerland. E-mail: urs.eiholzer@pezz.ch

PEDIATRICS (ISSN Numbers: Print, 0031-4005; Online, 1098-4275).

FINANCIAL DISCLOSURE: The authors have indicated they have no financial relationships relevant to this article to disclose.

FUNDING: No external funding.

POTENTIAL CONFLICT OF INTEREST: The authors have indicated they have no potential conflicts of interest to disclose.

WHAT'S KNOWN ON THIS SUBJECT: Levels of daily physical activity in children are decreasing worldwide. This implies risk factors for cardiovascular and metabolic diseases.

WHAT THIS STUDY ADDS: Strength training makes children not only stronger but significantly increases their daily spontaneous physical activity outside the training intervention.

abstract

BACKGROUND: In developed societies levels of daily physical activity (PA) among school-age children are decreasing. This implies risk factors for cardiovascular and metabolic diseases. Specific strategies to improve levels of PA are needed. In prepubertal boys there is evidence that strength training increases spontaneous PA outside of training.

METHODS: A total of 102 schoolchildren (age 10–14 years) in Switzerland were randomly assigned to physical education classes or to participate twice weekly at a guided strength training program for 19 weeks. Spontaneous PA energy expenditure (PAEE; 3axial accelerometry for 7 days), leg and arm strength, and body composition (dual energy radiograph absorptiometry) were measured at baseline, after 19 weeks of training intervention, and after 3 months of washout.

RESULTS: There were no significant differences between the groups at baseline. In the intervention group, PAEE increased by 10% from baseline to end of training in boys (P = .02), but not in girls. Leg and arm strength were increased owing to training intervention in both boys and girls. All other variables were unchanged. Baseline PAEE was significantly negatively correlated with changes of PAEE.

CONCLUSIONS: Targeted strength training significantly increases daily spontaneous PA behavior in boys. The less active children showed the greatest increase in spontaneous PAEE. Girls showed a similar increase in strength, but not in spontaneous PAEE. This may be explained by their earlier pubertal development. Strength training may be a promising strategy in schools to counteract decreasing levels of PA. *Pediatrics* 2013;132:1–7

In human history, satisfying hunger meant that people were forced to be physically active to get food and survive. During the last 50 years, as food supply became uncoupled from physical activity (PA), lifestyles changed from being physically active to being predominantly sedentary and inactive.[1] Because our genetic program did not change as fast as our lifestyle, PA changed from being a necessity into a primary preventive health measure for all ages. It is well established that PA reduces cardiovascular risk and helps protect against type 2 diabetes and some forms of cancer.[2] PA is also imperative for developing and maintaining muscle strength, joint function, and bone health. PA relies on muscular strength. Several studies showed that muscle strength also has significantly decreased over the past 20 years in children.[3,4] Today the majority of girls and a large proportion of boys fail to meet the minimum target of 60 minutes of at least moderate intensity PA per day.[5] Furthermore, PA declines as children get older.[6]

The arcuate nucleus of the hypothalamus is recognized as the brain's command center for controlling energy balance.[7] Along with other hypothalamic and brainstem nuclei, the neurons of the arcuate nucleus coordinate energy intake and expenditure. Although most reviews discussing the regulation of energy balance are focused on food intake, little is known about the regulation of spontaneous PA in childhood.

Recently we have shown in children who have Prader-Willi syndrome (PWS), as well as in healthy junior ice hockey players, that individually targeted strength training induces increased spontaneous PA outside of training. In children who have PWS, a complex genetic disorder causing a profound aversion to PA, we were able to show that the introduction of a 10-minute daily strength training led to a significant increase of spontaneous PA, with the daily walking distance improving from an average 3.7 to 5.8 km.[8] In 12- to 13-year-old ice hockey-playing boys we found that 16 weeks of strength training not only increases leg and arm strength, but also significantly increases spontaneous PA outside of training.[9]

The main objective of this randomized controlled intervention study was to assess whether participation in a school-based strength training program 2 hours per week would increase spontaneous daily PA outside of training in normal schoolchildren. We also wanted to test whether girls show a similar response to the training as boys, as our previous studies had only included boys. In addition, we wanted to examine whether the selected strength-training program is safe and whether it can be implemented easily by a school without using more resources than for normal physical education (PE) classes. The findings of this study could shed some light on what kind of interventions are effective to increase spontaneous daily PA in schoolchildren.

METHODS

This study was an individually randomized, controlled, school-based intervention study involving 102 schoolchildren (age 10–14 years) of a public primary and secondary school near Zurich, Switzerland. The study was approved by the Ethics Committee of the University Hospital of Zurich and, according to the institutional review board guidelines, informed consent was obtained from all participants and their parents. Two fifth and 4 seventh grade classes were selected. All girls and boys of these 6 classes were asked to participate. Those who were not able to take part in the normal PE classes for medical reasons, and therefore could not participate in a strength-training program, were excluded. Children who had a BMI above or below ±2.5 SDs or on stimulant medication such as methylphenidate participated in the normal PE classes and were involved in the measurements, but were excluded from analysis. Under the supervision of the researcher (UE) children of each grade were randomly assigned to the intervention or control group by drawing lots. Girls and boys were randomized separately to balance the groups. There was no other stratification.

The intervention took place during 2 of 3 regular PE classes and consisted of 45 minutes of individualized strength training for the whole body following the recommendations of the American Academy of Pediatrics, Committee on Sports Medicine and Fitness.[10]

Seven basic multiple-joint exercises were performed as a circuit in groups of 2: barbell back squat, barbell lunge squat, resistive-ball back extension, twisting crunch, barbell bench press, barbell bent over row, and barbell overhead press (Table 1, Supplemental Information I). Each session started with a 10-minute warm-up. Weights were introduced gradually when children had mastered proper technique. The weight was increased when the child was able to do more than 15 repetitions in the second set before reaching muscular exhaustion (60% of 1 repetition maximum). The PE teacher (RP), who was experienced in testing and training children, reviewed the workout logs during and after every session and made appropriate adjustments regarding training loads. Details of the training program are outlined in Table 2. During the training the ratio between teacher and children was at least 1 to 8 (2 instructors for 16 children). The control group and the children not participating in the study continued their normal PE classes at the same time as the intervention group.

TABLE 1 Training Equipment

Equipment/Exercise	Muscles Trained
Barbell back squat	Quadriceps, semitendinosus, semimembranosus, biceps femoris, gluteal
Barbell lunge squat	Quadriceps semitendinosus, semimembranosus, biceps femoris, gluteal, gastrocnemius, soleus
Resistive-ball back extension	Erector spinae system; uses body weight as a resistance
Twisting crunch	Straight and oblique abdominal muscles; uses body weight as a resistance
Barbell bench press	Pectorals, anterior deltoids, triceps
Barbell bent over row	Trapezius (middle and lower part), rhomboids, latissimus dorsi, teres major
Barbell overhead-press	Anterior deltoid, middle deltoid, trapezius, middle rhomboids

The study started in August, at the beginning of the new school year, and lasted until June. All children were tested 3 times: test 1 at baseline (August/September), test 2 after 19 school weeks at the end of the intervention (March), and test 3 at the end of a 3-month washout period after the intervention (June).

Height and weight were measured with standard techniques by using a Harpenden stadiometer (accuracy of measurement 1 mm) and an electronic balance (SECA708, Hamburg, Germany; d = 0.1 kg; CV, 0.055%), respectively. Children's anthropometric data are given as SD score (SDS) to scale them for comparison across ages and gender, according to the first Zurich Longitudinal Study.[11]

PA energy expenditure (PAEE) was objectively measured for 7 consecutive days by a body-fixed triaxial accelerometer (RT3, Stayhealthy, Monrovia, CA) in all participants. The accelerometer was worn following the manufacturer's instructions at all times, except during sleeping hours and when taking a bath or shower. Measurements of PAEE were analyzed by a single blinded examiner (FW). PAEE was derived by dividing the total sum of all activity measurements (kcal) recorded every minute by the total amount of minutes when the accelerometer was worn during the 7-day period. We had previously validated this method in children by using Deuterium water dilution and indirect calorymetry.[12]

Lean body mass (LBM) and fat mass (FM) were measured by dual energy radiograph absorptiometry (Hologic Discovery Wi, Bedford, MA). Children's LBM and FM are expressed as SDS.[13]

The maximum strength of the lower body was determined on a seated leg press (TECA, R.O.M. prestige, Ortona, Italy) and for the upper body on a Cybex smith press (Cybex; Owatonna, MN) by 1 repetition maximum testing. After a short standardized warm-up the participant performed the test with the maximum possible resistance (weight). All performance tests were conducted according to the protocol of Faigenbaum AD[14] by a single examiner (RP).

Skeletal maturity was assessed with the Tanner-Whitehouse 3 method.[15] Bone age (BA) was calculated based on a radiograph of the left hand and wrist.

All analyses were made in SPSS (version 9.0; IBM SPSS Statistics, IBM Corporation). Means and SDs were calculated for all variables. Student's *t* test was used to test differences between groups and univariate relationships were assessed with Pearson correlation analysis. Multiple regression analysis was used to test associations independently from possible confounding factors. P values <0.05 were considered to be significant.

TABLE 2 Training Execution

Number of repetitions	15 (20 for back extension and twisting crunch)
Time under tension per repetition	2- to 3-s concentric, 1-s rest, 2- to 3-s excentric
Range of motion	Full possible range of motion
Number of sets	2
Rest in between sets	2–3 min
Recovery time in between training sessions	Minimum 48 h
Number of exercise interventions per week	2
Weight increase	1 kg
Weight increase for squats	2 kg
Back extension and twisting crunch	First increasing number of reps, then adding another set

RESULTS

Descriptive Statistics

Out of the 112 schoolchildren, 105 consented to participate. One boy was excluded because he was on stimulant medication (methylphenidate); 2 were excluded for having BMI higher than +2.5 SDS. A total of 102 children (42 girls and 60 boys) were included in the study. At baseline there was no difference for any of the variables between the intervention and the control group. Girls' and boys' mean age was 11.9 (10.3–13.9) and 12.3 (10.1–14.1) years, respectively (Tables 3 and 4). Of the boys, 21 out of 32 in the intervention group and 17 out of 28 in the control group were prepubertal with a BA <13 years. Of the girls, 4 out of 22 in the intervention group and 4 out of 20 in the control group were prepubertal with a BA <11 years. Eighteen out of the 306 PA measurements were invalid, 6 for technical reasons and 12 for noncompliance (see Tables 3–5). No injuries occurred during the whole study period.

Group Analysis

Table 5 depicts the changes from baseline to the end of training intervention

TABLE 3 Descriptive Statistics Boys

	Boys		
	Intervention Group (*N* = 32)	Control Group (*N* = 28)	*P* Value
Age, y	12.4 (1.1)	12.2 (1.3)	.71
Height, cm	152.9 (8.3)	153.1 (10.5)	.93
Height, SDS	0.2 (1.0)	0.3 (1.0)	.72
Weight, kg	44.0 (10.2)	42.8 (10.0)	.66
Weight, SDS	0.8 (1.7)	0.6 (1.5)	.64
BMI	18.6 (2.9)	18.1 (2.5)	.44
BMI, SDS	0.4 (1.3)	0.2 (1.1)	.52
BA, y	12.2 (1.4)	12.2 (1.7)	.89
LBM, kg	32.3 (6.6)	31.9 (6.5)	.83
LBM, SDS	−1.0 (1.3)	−1.0 (1.2)	.82
FM, kg	9.4 (4.7)	8.7 (4.5)	.59
% FM, SDS	1.2 (0.6)	1.2 (0.6)	.62
Arm strength, kg	38.0 (10.6)	37.5 (8.5)	.85
Leg strength, kg	115.8 (22.7)	109.5 (17.8)	.24
PAEE, kcal/min[a]	1.03 (0.32)	1.16 (0.30)	.11

Data shown are mean (SD).

[a] *N* = 30 and *N* = 26 for boys' intervention and control group.

TABLE 4 Descriptive Statistics Girls

	Girls		
	Intervention Group (*N* = 22)	Control Group (*N* = 20)	*P* Value
Age	12.0 (1.1)	11.8 (1.1)	.53
Height, cm	152.5 (9.3)	150.0 (7.5)	.34
Height, SDS	0.5 (1.2)	0.3 (1.1)	.54
Weight, kg	42.0 (8.7)	40.7 (9.7)	.64
Weight, SDS	0.5 (1.1)	0.4 (1.3)	.97
BMI	17.9 (2.3)	18.0 (3.5)	.92
BMI, SDS	0.6 (1.1)	0.7 (1.7)	.85
BA, y	12.1 (1.4)	12.3 (1.6)	.76
LBM, kg	30.4 (5.7)	28.8 (5.0)	.34
LBM, SDS	−1.0 (1.1)	−1.3 (1.1)	.49
FM, kg	9.5 (3.6)	9.9 (5.2)	.78
% FM, SDS	0.5 (0.7)	0.6 (0.9)	.69
Arm strength, kg	32.7 (7.8)	33.4 (9.0)	.80
Leg strength, kg	107.1 (13.4)	104.8 (18.0)	.64
PAEE, kcal/min[a]	0.95 (0.29)	0.95 (0.31)	.99

Data shown are mean (SD).

[a] *N* = 21 and *N* = 19 for girls' intervention and control group.

and from baseline to the 3-month washout (see Supplemental Table 6 for table showing baseline, intervention, and washout data for all variables).

In the boys' intervention group, PAEE significantly increased by 10% from baseline to the end of training. The mean change in PAEE from baseline to the end of training was significantly higher in the intervention group compared with the control group. PAEE was unchanged between the groups from baseline to 3-month follow-up after washout period. In the intervention group, upper and lower body strength increased by 38% and 36%, respectively, while in the control group upper and lower body strength increased by 11% and 7%, respectively, from baseline to the end of training intervention, the differences between the groups being highly significant. At the end of the 3-month washout period however, upper and lower body strength of both groups showed no significant differences anymore. Age-corrected LBM slightly increased in the intervention group from baseline to the end of training intervention; however, when comparing the groups, LBM was unchanged. Age-corrected relative FM was unchanged across the study and between the groups.

In girls, PAEE remained unchanged in both the intervention and control group throughout the study. The intervention group showed an increase in upper and lower body strength by 33% and 29%, whereas in the control group upper and lower body strength increased by 12% and 9% from baseline to the end of training intervention. Again the difference between the groups was highly significant. After 3-month washout, however, no differences in upper and lower body strength between the groups were apparent. At the end of the training period, age-corrected LBM showed a non-significant decrease in the intervention group (−0.1 SDS, +1.1 kg) and a non-significant increase in the control group (+0.1 SDS, +2.0 kg), the differences between the groups being significant ($P = .02$). At the end of training intervention, relative FM significantly ($P = .03$) increased in the intervention group (+1.0%) compared with the control group (+0.3%).

Covariable Analysis

Entire group correlation analysis of baseline variables revealed a positive correlation between PAEE and chronological age ($r = 0.27$, $P < .05$) and an even stronger correlation between PAEE and BA ($r = 0.43$, $P < .05$). A separate gender analysis showed a correlation with BA for boys ($r = 0.46$, $P < .001$) but not for girls ($r = 0.43$, $P < .05$).

After correcting PAEE for BA, the changes between the groups from baseline to the end of training intervention and from baseline to 3-month follow-up were recalculated. The results remained unchanged; boys but not girls significantly increased PAEE.

TABLE 5 Changes in Main Outcome Measures

	Boys					Girls				
	Intervention Group	*n*	Control Group	*n*	*P* Value Between Groups	Intervention Group	*n*	Control Group	*n*	*P* Value Between Groups
PAEE, kcal/min*										
Intervention	0.11 (0.20)*	29	−0.05 (0.28)	26	.02	−0.03 (0.20)	20	0.01 (0.28)	18	.59
Washout	0.01 (0.32)	26	0.09 (0.38)	23	.43	0.07 (0.38)	21	0.01 (0.29)	19	.55
Arm strength, kg										
Intervention	14.4 (4.7)*	32	4.1 (2.1)*	28	<.001	12.4 (3.7)*	22	3.9 (2.0)*	20	<.001
Washout	7.2 (3.3)*+	32	7.5 (3.3)*+	28	.77	5.7 (3.6)*+	22	6.7 (3.6)*+	20	<.001
Leg strength, kg										
Intervention	41.6 (14.8)*	32	8.0 (6.0)*	28	<.001	35.2 (9.0)*	22	9.5 (5.3)*	20	<.001
Washout	19.1 (8.8)*+	32	15.9 (8.2)*+	28	.16	17.4 (8.2)*+	22	17.6 (8.3)*+	20	.93
LBM SDS										
Intervention	0.2 (0.5)*	32	0.1 (0.4)	28	.58	−0.1 (0.3)	22	0.1 (0.4)	20	.02
Washout	0.1 (0.4)	32	0.1 (0.4)	28	.68	0.1 (0.4)+	22	0.2 (0.3)*	20	.18
FM, %										
Intervention	−0.3 (2.1)	32	−0.1 (2.8)	28	.71	1.1 (2.2)*	22	−0.6 (2.6)	20	.03
Washout	−0.6 (2.0)	32	−0.4 (3.2)	28	.75	0.3 (2.6)	22	−0.7 (2.0)	20	.17

Data shown are mean (SD) changes from baseline.
Within group comparison:
* $P < .05$ from baseline;
+ $P < .05$ from end of intervention.
Not significant for $P > .05$.

We then tested whether the changes of PAEE from baseline to the end of training intervention could be associated with baseline covariates. PAEE did not correlate with age, BA, upper or lower body strength, LBM, or FM at baseline in any of the groups. At the end of training intervention only baseline PAEE was significantly negatively correlated with changes of PAEE ($r = -0.45$, $P < .001$).

DISCUSSION

Over the last decades there has been a continuing reduction in physical fitness in children and adolescents.[16–18] Lack of PA increases the risk for obesity, metabolic and cardiovascular diseases, and orthopedic problems.[2] Decreasing PA in children may even have a negative impact on PA behavior during adult life as well.[19]

Our study in healthy schoolchildren aged 10 to 14 years shows that an individualized school-based strength-training program makes boys and girls stronger and significantly increases daily spontaneous PA outside the training intervention in boys.

Recently we have shown in children who have PWS who have a profound aversion to PA, as well as in healthy junior ice hockey players, that individually targeted strength training induces increased spontaneous PA outside of training.[8,9] For the current study, 102 healthy schoolchildren were randomly placed in 2 groups. The control group continued 3 PE classes per week, whereas the intervention group had 2 out of 3 PE classes replaced by an individualized strength-training program. At baseline there was no difference in anthropometry, body composition, and PAEE between the groups. At the end of the training intervention, we found a significant increase of upper and lower body strength in the intervention group in boys and in girls. Boys significantly increased their PA by 0.11

kcal/min or 10%. Without taking into account the energy expenditure during the strength training, the 10% PAEE increase corresponds to a weekly bike ride of 2.5 hours corresponding to 45 km for a child of 40 kg body weight. In other words, an individualized school-based strength-training program increases energy expenditure outside the intervention by an equivalent of ~7 kg of body fat corresponding to 10 kg of chocolate per year.

In our study girls and boys trained together and qualitatively had the same strength-training program. Although the girls were equally motivated and achieved a comparable increase of upper and lower body strength, they showed no increase in spontaneous PA at the end of the training intervention. We attribute this gender difference to the maturational differences between girls and boys. On average, puberty begins at age 11 years in girls and at age 13 years in boys. Most of the girls we studied were therefore pubertal (mean BA 12.2 years) in contrast to the boys who were mainly prepubertal (mean BA 12.2 years).

Corder et al measured PA behavior among 10-year-old British children (age 10.2 ± 0.3 years) and again 1 year later; PA decreased over 1 year, particularly among girls and on weekends.[20] That the onset of puberty may be responsible for changing patterns of PA from a child regulation to an adult one is supported by our previous observation in junior ice hockey players, in whom the positive correlation between training intensity and spontaneous PA was lost with the onset of puberty.[12] The regulatory interplay of factors controlling PA seems to change from childhood to adulthood. Contrary to what we described in prepubertal ice hockey playing boys and school boys, it seems that exercise interventions in adults (in particular high-intensity exercise) do not affect spontaneous PA.[16–18] In obese adults, induced exercise was even shown to be negatively compensated by a reduction of spontaneous PA outside of training hours.[21] Future studies are needed to explore differences of regulation of PA between children and adults and to show whether individualized strength training increases PA in prepubertal girls.

As expected, LBM and FM did not significantly change in boys owing to strength training. In girls the changes of body composition were also expected; pubertal girls increase the percentage of body fat and accrue FM at a rate of 1.14 kg/year.[22] The differences between the groups were statistically significant. This may be explained because the girls in the control group were closer to the peak of their pubertal growth spurt; indeed they grew a bit faster than the girls in the intervention group (+0.5 cm).

Covariable analysis showed that the strength-training program was most efficient for the children who had the lowest PA. This is in line with our results in children who have PWS. They have very low PA and increased their spontaneous PA in response to a strength-training intervention by 57%.[8] In prepubertal children, less specific types of strength-training interventions are also able to increase PA. Sigmund et al showed that 45 minutes more PE including high-intensity activities such as jumps, hops, and sprints also increases leisure time PA.[23] The mechanism by which strength training induces spontaneous PA remains unclear. There may be an endocrine signaling coming from the musculoskeletal system, which is responsible for a positive feedback between physical strength and PA. However, the physiologic importance of the homeostatic control of food intake and body weight, located in the central nervous system, is well known as discussed by Morton et al, for example.[24] We hypothesize that the central control of energy balance located in the hypothalamic nuclei also integrates information about physical capacity and overall physical strength. It seems that a new strength status of a person can induce adaptive adjustments of behavioral patterns and may affect activity levels directly.

If supervised by a qualified teacher, strength training is safe as already shown by others.[25] No injuries occurred throughout the study period. Research increasingly indicates that strength training might be an optimal measure for children increasing musculoskeletal health and self-confidence.[26,27] Schools are well suited to introduce children to strength training as they spend most of their time there and such activities are also much more attractive for children if carried out together with schoolmates. The cost of the equipment required for strength training is low.

CONCLUSIONS

Identifying factors related to changes in PA is an important step in developing interventions to stop decreases in PA levels during childhood. This randomized controlled trial shows that an individualized school-based strength-training program in prepubertal boys increases daily spontaneous PA outside the training. The impact is likely to fade with the onset of puberty. The girls in this study showed the same increase in upper and lower body strength, which suggests that they were similarly motivated, but no increase in daily spontaneous PA, which may be explained by their earlier pubertal development.

Further research is needed to understand the factors that influence PA in prepubertal and pubertal children and to find out what adequate training stimulus is needed to have a lasting impact on PA behavior.

ACKNOWLEDGMENTS

We thank the children, their parents, and the teachers of the School in Zollikon, Switzerland, for participation and the great support. We thank Dr Lara Ogunshola for proofreading our manuscript. We thank the "Stiftung Wachstum Pubertät Adoleszenz" for their support.

REFERENCES

1. Dumith SC, Hallal PC, Reis RS, Kohl HW III. Worldwide prevalence of physical inactivity and its association with human development index in 76 countries. *Prev Med*. 2011;53(1-2):24–28
2. Warburton DE, Nicol CW, Bredin SS. Health benefits of physical activity: the evidence. *CMAJ*. 2006;174(6):801–809
3. Runhaar J, Collard DC, Singh AS, Kemper HC, van Mechelen W, Chinapaw M. Motor fitness in Dutch youth: differences over a 26-year period (1980-2006). *J Sci Med Sport*. 2010;13(3):323–328
4. Cohen DD, Voss C, Taylor MJ, Delextrat A, Ogunleye AA, Sandercock GR. Ten-year secular changes in muscular fitness in English children. *Acta Paediatr*. 2011;100 (10):e175–e177
5. Butcher K, Sallis JF, Mayer JA, Woodruff S. Correlates of physical activity guideline compliance for adolescents in 100 U.S. cities. *J Adolesc Health*. 2008;42:360–368
6. Hallal PC, Andersen LB, Bull FC, Guthold R, Haskell W, Ekelund U; Lancet Physical Activity Series Working Group. Global physical activity levels: surveillance progress, pitfalls, and prospects. *Lancet*. 2012;380 (9838):247–257
7. Riediger T. The receptive function of hypothalamic and brainstem centres to hormonal and nutrient signals affecting energy balance. *Proc Nutr Soc*. 2012;71(4): 463–477
8. Schlumpf M, Eiholzer U, Gygax M, Schmid S, van der Sluis I, l'Allemand D. A daily comprehensive muscle training programme increases lean mass and spontaneous activity in children with Prader-Willi syndrome after 6 months. *J Pediatr Endocrinol Metab*. 2006;19(1):65–74
9. Eiholzer U, Meinhardt U, Petro R, Witassek F, Gutzwiller F, Gasser T. High intensity training increases spontaneous physical activity in children: a randomized controlled study. *J Pediatr*. 2010;156(2):242–246
10. Bernhardt DT, Gomez J, Johnson MD, et al; Committee on Sports Medicine and Fitness. Strength training by children and adolescents. *Pediatrics*. 2001;107(6):1470–1472
11. Prader A, Largo RH, Molinari L, Issler C. Physical growth of Swiss children from birth to 20 years of age. First Zurich longitudinal study of growth and development. *Helv Paediatr Acta, Suppl*. 1989;52(suppl 52):1–125
12. Eiholzer U, Meinhardt U, Rousson V, et al. Association between short sleeping hours and physical activity in boys playing ice hockey. *J Pediatr*. 2008;153:640–645
13. van der Sluis IM, de Ridder MA, Boot AM, Krenning EP, de Muinck Keizer-Schrama SM. Reference data for bone density and body composition measured with dual energy x ray absorptiometry in white children and young adults. *Arch Dis Child*. 2002;87(4):341–347
14. Faigenbaum AD, McFarland JE, Herman RE, Naclerio F, Ratamess NA, Kang J, Myer GD. Reliability of the one-repetition-maximum power clean test in adolescent athletes. *J Strength Conditioning Res*. 2012;26:432–437
15. Tanner JM. *Assessment of Skeletal Maturity and Prediction of Adult Height (TW3 Method)*. 3rd ed. London, United Kingdom: WB Saunders; 2001
16. Ekelund U, Sardinha LB, Anderssen SA, et al. Associations between objectively assessed physical activity and indicators of body fatness in 9- to 10-y-old European children: a population-based study from 4 distinct regions in Europe (the European Youth Heart Study). *Am J Clin Nutr*. 2004;80(3):584–590
17. Saxena R, Borzekowski DL, Rickert VI. Physical activity levels among urban adolescent females. *J Pediatr Adolesc Gynecol*. 2002;15(5):279–284
18. Tomkinson GR, Léger LA, Olds TS, Cazorla G. Secular trends in the performance of children and adolescents (1980-2000): an analysis of 55 studies of the 20m shuttle run test in 11 countries. *Sports Med*. 2003; 33(4):285–300
19. Azevedo MR, Araújo CL, Cozzensa da Silva M, Hallal PC. Tracking of physical activity from adolescence to adulthood: a population-based study. *Rev Saude Publica*. 2007;41(1):69–75
20. Corder K, van Sluijs EM, Ekelund U, Jones AP, Griffin SJ. Changes in children's physical activity over 12 months: longitudinal results from the SPEEDY study. *Pediatrics*. 2010;126(4). Available at: www.pediatrics.org/cgi/content/full/126/4/e926
21. Kempen KP, Saris WH, Westerterp KR. Energy balance during an 8-wk energy-restricted diet with and without exercise in obese women. *Am J Clin Nutr*. 1995;62(4): 722–729
22. Rogol AD, Roemmich JN, Clark PA. Growth at puberty. *J Adolesc Health*. 2002;31:192–200
23. Sigmund E, El Ansari W, Sigmundová D. Does school-based physical activity decrease overweight and obesity in children aged 6-9 years? A two-year non-randomized longitudinal intervention study in the Czech Republic. *BMC Public Health*. 2012;12:570
24. Morton GJ, Cummings DE, Baskin DG, Barsh GS, Schwartz MW. Central nervous system control of food intake and body weight. *Nature*. 2006;443(7109):289–295
25. Faigenbaum AD, Myer GD. Resistance training among young athletes: safety, efficacy and injury prevention effects. *Br J Sports Med*. 2010;44:56–63
26. Faigenbaum AD, Kraemer WJ, Blimkie CJ, et al. Youth resistance training: updated position statement paper from the National Strength and Conditioning Association. *J Strength Conditioning Res*. 2009;23(5 Suppl): S60–S79
27. Löfgren B, Daly RM, Nilsson JA, Dencker M, Karlsson MK. An increase in school-based physical education increases muscle strength in children. *Med Sci Sports Exerc*. 2013;45 (5):997–1003