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Original article

Title:

Twice weekly, in-school jumping improves lean mass, particularly in adolescent boys

Running Title:

Brief jumping bouts improve lean mass in boys

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ABSTRACT

Objective: To determine the effect of a twice-weekly, school-based, 10 minute jumping regime on muscle and fat tissue in healthy adolescent boys and girls. **Methods:** We replaced regular warm up activities with jumping in physical education (PE) classes of early high school students for 8 months to observe the effect on muscle and fat tissue. A total of 99 adolescents (46M, 53F; 13.8 ± 0.4 years) volunteered to participate. Intervention group subjects performed ten minutes of varied jumping activity, while control subjects performed a regular PE warm-up. Biometrics, Tanner staging, age of peak height velocity (PHV), vertical jump, whole body lean tissue, and fat mass (DXA-derived) were measured at baseline and follow-up. Physical activity was determined by questionnaire. **Results:** There were no differences in any measured variable between control and intervention groups at baseline. Boys had a significantly older age of PHV than girls ($p = 0.02$). No group differences were detected for 8-month change in height, weight or maturity measures for the combined sample; however at 8-months jumpers had accrued greater lean tissue mass than controls ($p = 0.002$). Sex-specific analysis revealed that intervention group boys had gained more lean tissue mass than controls ($p = 0.016$) and experienced significant fat loss ($p = 0.010$) than controls, an effect that was not observed in the girls. **Conclusion:** Regular, short duration, jumping activity during adolescence increased lean tissue mass and boys additionally lost fat mass. Sex-specific and/or maturation-specific factors may explain the disparity in effect.

Key words: adolescent; children; exercise; fat mass; jumping; lean mass; physical activity.

INTRODUCTION

The dramatic rise in prevalence of chronic diseases, such as obesity, cardiovascular disease, and musculoskeletal conditions, has been paralleled by a reduction in levels of physical activity among children and adolescents. The prevalence of obesity in childhood is increasing at an alarming rate in Australia [1] and across the world [2]. Reports from the United States indicate that approximately one third of American children and adolescents are overweight or obese [3]. Even during childhood, the physical and psychological morbidity associated with overweight is considerable [4]. The combination of factors; population growth, an ageing population, and the rapidly increasing prevalence of obesity at all ages, exerts enormous and growing pressure on healthcare systems. Thus, there is an urgent need to identify effective strategies to prevent overweight during childhood that are easy to implement at the community level.

Childhood has long been recognized as a critical ‘window of opportunity’ for instilling healthy lifetime behaviors [5]. Physical activity in particular, is an easily modified lifestyle factor influencing myriad health outcomes. Gender-dependent relationships of bone mass [6] and body composition [7] to physical activity are apparent during puberty; however sex-specific muscle and fat responses have not been well described. In particular, the nature and dose of exercise that will optimize the body composition of girls and boys (collectively or in a sex-specific manner) during growth are yet to be elucidated. It is well-recognised that benefits will only be derived from exercise intervention if adequate compliance is achieved [3]. Individual interventions involving healthy lifestyle behaviors such as exercise or diet are particularly limited by poor adherence. By contrast, schools provide an opportune setting to maximize large scale and long term childhood compliance with simple exercise interventions.

A recent meta-analysis of in-school physical activity interventions reported equivocal outcomes for body composition and BMI [8]. However, most of the interventions reviewed would be classified as low or moderate intensity and would thus fall below the threshold required to modify body composition. Furthermore, most physical activity interventions for obesity prevention have been conducted in primary school age children [9] so that the potential benefits to adolescents remain largely unknown. In fact, recent data indicates that physical activity in American children decreases after the age of six, suggesting older children and adolescents may be particularly at risk [10]. Other investigators have examined such a broad range of physical activities, and in conjunction with educational, nutritional, or social interventions [11-13], that the specific effect of any particular physical activity on body composition has not been possible to determine.

The aim of the current study was to determine the effect of a regular, brief, in-school jumping regime on muscle and fat mass in healthy adolescent boys and girls, in comparison with controls. We hypothesized that (1) adolescents participating in high intensity jumping activities would have greater gains in lean tissue than controls, (2) adolescents participating in the high intensity jumping activities would lose more fat mass than controls, and (3) boys and girls would experience similar effects.

MATERIALS AND METHODS

Study Design

The study was a prospective eight-month, randomized, controlled, school-based, exercise intervention. Exercise sessions took place every week of the school year with the exception of school holidays and study testing periods. Baseline testing occurred at the beginning of the school year and follow up testing was completed in the final weeks of the

school year. Ethical approval was obtained from the Griffith University Human Research Ethics Committee (Protocol #PES/09/05/HREC) and Education Queensland (Queensland Government Department for Education, Training and the Arts).

Subjects and subject selection

Adolescents enrolled in the ninth grade of a local high school (Gold Coast, Australia) were recruited to participate in the trial. Subjects were included if they were of sound general health, fully ambulatory, and had the written consent of a parent or guardian. Subjects were excluded from the study if they had a endocrine disorder, metabolic disease, or chronic renal pathology, were taking medications known to affect the musculoskeletal system, were recovering from lower limb injury, or were affected by any condition not compatible with intense physical activity. Participants were randomized to either control or intervention groups.

Intervention

The intervention group participated in ten minutes of supervised jumping activity at the start of each physical education (PE) class, that is, twice per week for eight months, excluding holidays. Each bout of jumping comprised at least some of the following manoeuvres: jumps, hops, tuck-jumps, jump-squats, stride jumps, star jumps, lunges, side lunges, and skipping. A typical ten-minute session included approximately 300 jumps performed at approximately 1-3 Hz and at a height of 0.2-0.4 metres, although these figures were achieved gradually in order to reduce the risk of injury and apply progressive overload. The instructor (BW) demonstrated all jumping activities and co-ordinated the routine at each session. Jumping sessions were occasionally supplemented with upper limb strengthening

activities, such as push-ups and exercises with resistive bands (AusBand, Ausmedic Australia, Pty. Ltd.).

Control activities

Control group subjects undertook regular PE warm-ups and stretching directed by their usual PE teacher at a time that corresponded with intervention group activities, that is, at the beginning of every PE class, twice per week for a period of eight months, excluding holidays. Control activities were focused on improving flexibility and general preparedness for physical activity. Activities typically included brisk walking, light jogging, and stretching. All subjects regrouped for normal PE activities directly after the diverse warm ups had been completed. Intervention and control groups met at separate locations not visible to each other. Teachers performed a roll call at the start of every PE session to confirm student attendance in the correct location and prevent intervention contamination.

Testing

Testing took place at baseline and follow-up (i.e. 8 months) and included anthropometrics, determination of maturation, assessment of muscle power, and body composition measurements using dual energy x-ray absorptiometry (DXA). Physical activity questionnaires were completed during PE classes in the same week as testing.

Anthropometrics

Standing height and sitting height were measured to the nearest millimetre using the stretch stature method with a portable stadiometer (HART Sport & Leisure, Australia). Weight was measured to the nearest 0.1 kilogram using the mean of measures from two sets of digital scales (Soehnle Co., Switzerland) as a quality control measure. Body mass index

(BMI) was determined from measures of height and weight per the accepted method (BMI = $\text{weight} \cdot \text{height}^{-2}$, $\text{kg} \cdot \text{m}^{-2}$).

Physical maturity

Maturity was determined using two methods. The first involved self-determination of Tanner stage using standard diagrams of pubic hair growth (and breast development for females). Privacy was maintained from other subjects and investigators by providing booths for completing forms and sealed, coded envelopes for submission.

The second method was that of Mirwald and colleagues [14] who formulated an algorithm using data from a large paediatric longitudinal trial [15] to predict age of peak height velocity (APHV) based on a single measurement of several anthropometric parameters (i.e. height, sitting height, and body mass) and chronological age. Years from APHV was used to align subjects (i.e. boys and girls) on a common maturational milestone and thus, control for the influence of biological maturity on results.

Body composition

Measures of whole body bone-free lean tissue and fat mass were made with an XR-36 Quickscan Densitometer (Norland Medical Systems, Inc., USA) using host software, version 3.9.4, and scanner software version 2.0.0. The same investigator (BW) performed and analyzed all DXA measurements.

Muscle power

Muscle power was determined using a vertical jump test. The Yardstick (Swift Sports Equipment, Lismore, NSW, Australia) was used to determine vertical jump height as the difference between the height of a standing reach and total jump height. The subject stood

with feet shoulder width apart, preferred arm raised and non-preferred arm kept to the side of the body. A jump for maximum height was made in a countermovement fashion without arm swing. The best of three attempts was recorded to the nearest centimetre.

Physical activity

A physical activity score was derived for each subject, from responses to a physical activity questionnaire [16] using a custom-designed LabVIEW program (National Instruments, Texas, USA) to account for the type, frequency and years of physical activity participation.

Statistical analyses

Statistical analyses were performed using SPSS version 17.0 for Windows (SPSS, Chicago, IL, USA). Two-tailed Pearson correlation analyses were employed to observe relationships between physical/lifestyle characteristics and eight-month change in muscle and fat parameters. An intention-to-treat repeated-measures ANOVA adjusting for APHV was used to examine treatment effects. Within-group effects were also examined. A power analysis indicated that for 80% power, a minimum of 82 subjects would be required to detect a 2.5 kg difference in fat mass, with a standard deviation of 4.0 kg and an alpha level of 0.05 [17].

As differences in physical and maturational characteristics existed between sexes at baseline, the data were further analyzed according to sex. Baseline characteristics of those who dropped out of the study and those who remained were compared using independent t-tests. Statistical significance was set at $p < 0.05$.

RESULTS

Subject characteristics

A total of 99 adolescents (mean age 13.8 ± 0.4 years) consented to participate in the trial. At baseline, there were 46 boys (mean age 13.8 ± 0.4 years) and 53 girls (mean age 13.7 ± 0.4 years) in the study. Fifty-two (22 boys, 30 girls) were randomized to the intervention group and 47 (24 boys, 23 girls) to the control group (Figure 1). Eighteen subjects were lost prior to follow up testing due to geographic relocation or absence on the day of testing. Ultimately, 81 adolescents (43 intervention, 38 control) were included in the final analysis at eight months (Figure 1). Baseline characteristics of those lost to follow up did not differ from the remaining cohort.

A number of sex differences were observed at baseline ($n = 99$). Boys were heavier, taller, and had greater vertical jump performance than girls ($p < 0.05$). Boys had significantly greater lean mass (37380 ± 8390 g vs 30585 ± 3736 g; $p < 0.002$) and lower percent body fat (22.0 ± 8.6 vs 27.7 ± 5.7 ; $p < 0.002$). There were no sex differences in physical activity scores. All Tanner stages were represented in both boys and girls; however the majority were peripubertal with 53 % classified Tanner IV. APHV was significantly older for boys (13.8 ± 0.1 years) than girls (12.3 ± 0.1 years), therefore boys were significantly fewer years from APHV (0.0 ± 0.1 years) than girls (1.5 ± 0.1 years). Average age of menarche for girls was 12.5 ± 0.7 with eleven still premenarcheal at the time of baseline testing.

Given the observed sex differences in physical characteristics and maturity at baseline, sex-specific analyses were performed in addition to the whole sample analysis. At

baseline, boys exhibited no significant between group differences for any physical characteristic; however sitting height for girls was significantly greater at baseline in the intervention group than the control group (0.852 ± 0.026 m vs 0.828 ± 0.030 m; $p = 0.02$).

Body composition effects

Table 1 presents intention-to-treat data for within- and between-group effects for the entire cohort ($n = 99$).

Intervention subjects developed significantly greater bone-free lean mass than control subjects at follow up ($p = 0.002$; $1-\beta = 0.86$). Body mass index (BMI) increased significantly for both intervention ($p = 0.001$) and control groups ($p = 0.006$) with no difference between groups at 8 months ($p = 0.895$). Despite a 2.5% reduction in fat mass in intervention subjects, there was no between-group difference at follow up ($p = 0.929$; $1-\beta = 0.27$). As the absolute difference in fat mass between the treatment and control groups was less than the effect size in the power analysis, significance was not reached. Similarly there was no between-group difference in percent fat at follow-up ($p = 0.323$); however within-group analysis revealed that intervention subjects experienced a significant reduction in percent fat over the course of the study ($p = 0.001$), while controls did not ($p = 0.051$).

Sex-specific observations

Eight-month change in biometrics

Eight-month change in biometrics is presented in Table 2 for boys and Table 3 for girls, with no between group differences evident. Boys in both groups increased weight and height ($p < 0.05$), but did not change body mass index. Girls experienced significant gains in weight, height, and body mass index ($p < 0.05$) over the eight-month period.

Eight-month change in muscle and fat

Eight-month change in bone-free lean and fat mass is presented in Tables 2 and 3. Boys in both groups experienced significant increases in bone-free lean mass (+4.0% control and +8.9% intervention) with between-group differences at follow up ($p = 0.016$; $1-\beta = 0.86$). Boys in the intervention group experienced a significant reduction (-6.7%, $p = 0.01$) in fat tissue mass, while controls experienced no change (-0.3%, $p > 0.05$; $1-\beta = 0.47$). Girls in both groups experienced significant increases in bone-free lean tissue mass (+2.3% control and +3.8% intervention), with no differences in degree of change between groups. Fat tissue mass did not change in either female group over the eight-month duration of the study ($p > 0.05$). For the intervention group, change in bone-free lean tissue mass was inversely related to biological maturity (i.e. years from age of PHV) ($r = -0.29$, $p = 0.004$) (Figure 2), but not for the control group. There was no relationship between change in fat mass and maturity for any group.

Eight-month change in physical and lifestyle characteristics

Boys in both groups did not change physical activity level external to trial activities over the eight-month duration of the study ($p > 0.05$). Vertical jump improved significantly for boys in both groups (+8.2% control and +8.9% intervention), with no difference in degree of change between groups. Girls in the control group increased their external physical activity level (+28.9%, $p = 0.003$), while girls in the intervention did not (-13.6%, NS); a between-group difference that was significant ($p = 0.008$). No difference was observed for eight-month change in vertical jump for girls in either group ($p > 0.05$).

Compliance

The overall subject dropout rate was 18%. Mean compliance for the intervention was 80%. There were no differences in baseline physical characteristics or body composition between those who dropped out and those who remained in the program.

DISCUSSION

Our goal was to determine the effect of a simple, short duration, in-school jumping regime on body composition in healthy adolescent boys and girls. We found that adolescents in the jumping group improved bone-free lean mass. Observed differences between groups with respect to changes in fat mass likely did not reach significance due to inadequate power. Given the brevity of the intervention activity, particularly impressive results were revealed for boys who gained substantial amounts of bone-free lean tissue and lost notable amounts of fat mass. We also observed that collectively, intervention group changes in lean tissue mass were inversely related to physical maturity, that is, the greatest changes occurred in the least physically mature boys and girls.

A recent meta-analysis concluded that school-based physical activity interventions did not improve BMI in children [8]. Our data support this observation as there was no change in BMI for boys and the BMI for girls actually increased. As BMI is dependent on weight and height only, it does not account for the relative contribution of lean and fat tissue to weight, nor does it account for the distribution of fat mass. Despite unremarkable effects on BMI, we found significant benefits of our intervention for both lean and fat mass for boys in the jumping group. Findings highlight the known pitfalls of using BMI as a surrogate for body composition.

Our data suggest that either adolescent male lean and fat tissue is more responsive to brief bouts of high intensity jumping intervention than that of age-matched girls, or that muscle tissue is most sensitive to jumping activity in adolescents nearest to the time at which they are growing most rapidly. As PHV coincides with peak circulating concentrations of factors such as growth hormone and insulin-like growth factor 1 (IGF-1), the musculoskeletal system is likely to be most sensitive to loading at this time [18]. Although haematological factors were not measured in the current study, that boys in the cohort were closer to PHV than girls, and exhibited the greatest changes in lean and fat tissue in response to the intervention suggests potent anabolic and lipolytic growth-related hormone effects played a role in the response. Boys and girls appeared to participate at similar levels of intensity; however future studies should include heart rate monitoring and ratings of perceived exertion to validate those observations. It is also possible that the increase in external physical activity observed in control group girls over the study period obscured intervention-specific changes in lean mass the jumping group.

Aside from the most obvious explanation for the favourable body composition changes in the male intervention group (jumpers expended more energy than controls), the minimal duration exposure of the intervention suggests that other factors contributed to fat loss. Metabolic rate has long been linked with weight gain, and known to be modulated by the sympathetic nervous system [19]. Given the high intensity exercise nature of our protocol, sympathomimetic effects cannot be ruled out. As lean tissue mass is positively related to resting metabolic rate [20], it is possible that the greater accumulation of lean tissue in boys in the intervention group might have enhanced loss of fat by indirectly increasing resting metabolic rate and associated utilization of fatty acids over the course of the year. In addition, the enzymatic changes that occur in skeletal muscle following high intensity

exercise favour reduced body fat deposition and increased lipid oxidation, thereby compounding positive effects as the intervention progressed [21-22].

Corresponding to lean tissue changes, students in both groups improved their vertical jump performance although changes were not significant for girls. As boys were closer to PHV, and thus growing more rapidly than girls, this finding is not unexpected. Curiously, physical activity level increased for girls in the control group. It is possible this additional physical activity participation diluted the effect of the intervention for girls and also obscured between-sex comparisons.

Other school-based exercise interventions that have resulted in positive changes in body composition have involved extending the total duration of in-school exercise or introducing additional classes [23-26]. For example, in a study of 53 Swedish primary school children, increasing the duration of physical education from 60 minutes to 200 minutes per week caused a greater increase in regional lean mass in the intervention group than controls [26]. Likewise, a study of 3,086 Chilean primary school children introduced an additional 90 minutes of physical activity per week alongside a nutrition education block for six months and found a positive effect on adiposity in boys, but not girls [24] - a sex-specific effect that was observed in the current study. In a cluster randomized trial of 502 Swiss school children, adding two PE classes, 'physical activity breaks' between lessons, and 'physical activity homework' led to improved aerobic fitness and adiposity (skinfolds) after one year in the intervention group [25]. We have shown that a far less intrusive strategy of simply replacing a 10-minute PE warm-up session with high intensity activity can be easily implemented and similarly effective.

In conclusion, eight months of short duration, high intensity jumping during year 9 PE classes affected positive changes in whole body bone-free lean and fat tissue composition in a sex-specific manner. Boys gained muscle mass and had a tendency to lose fat, while girls did

not. Thus, our simple, practical in-school exercise intervention engendered improvements in musculoskeletal health in boys without the need for additional staffing or equipment and with minimal disruption to daily school activities. Longitudinal studies are required to determine if the benefits persist long enough to aid the prevention of obesity and other chronic disease in later life.

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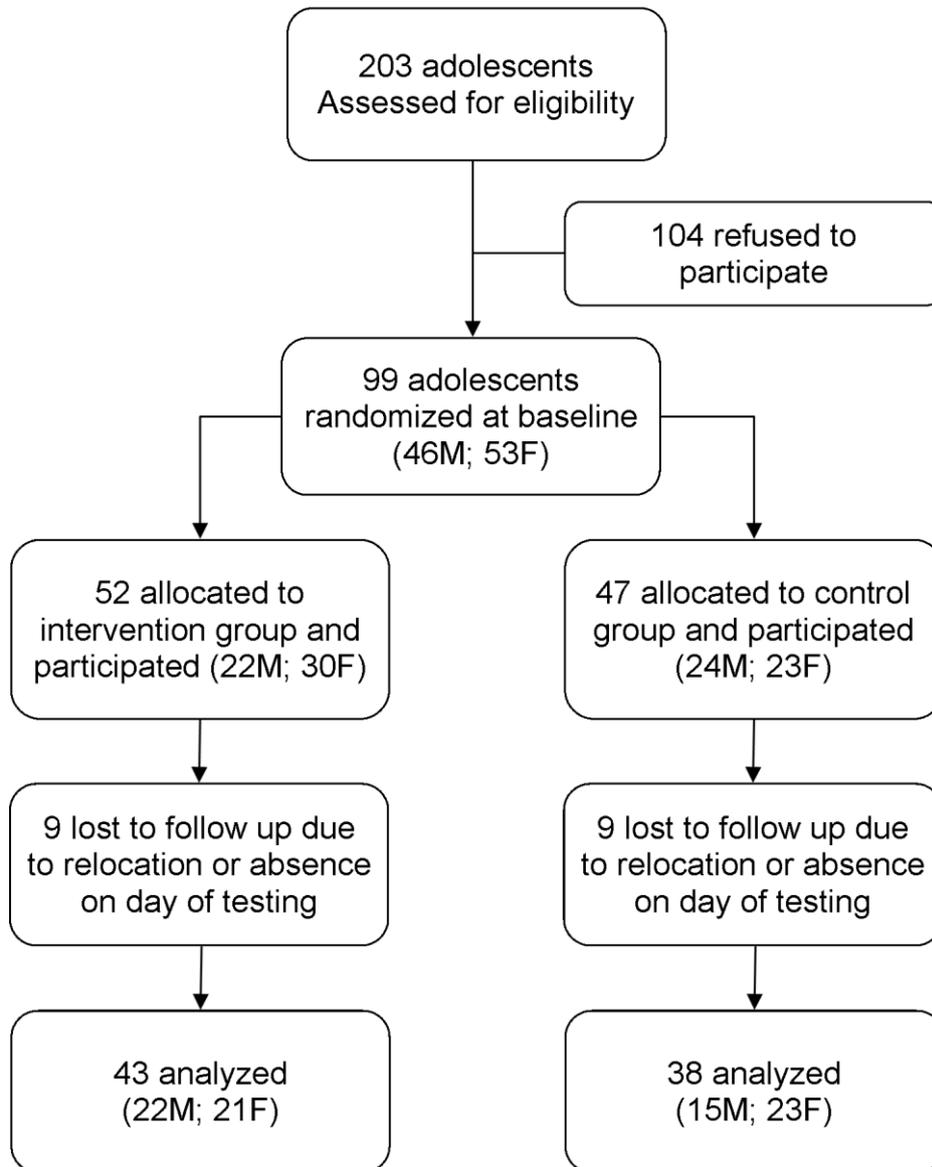


Figure 1

CONSORT diagram of subject flow through the trial.

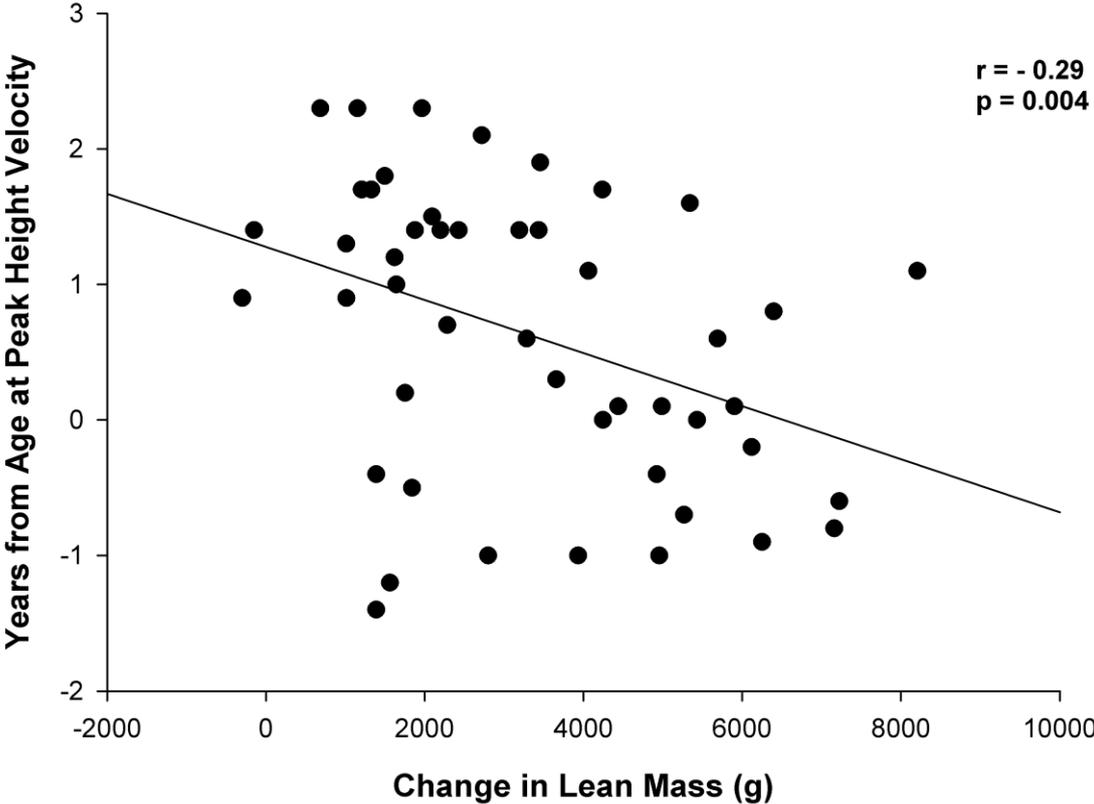


Figure 2
Change in bone-free lean mass vs. years from age at peak height velocity for boys and girls in the intervention group.

Table 1**Eight-month intention-to-treat body composition findings (mean \pm SD) for all boys and girls in the study cohort (n = 99).**

Parameter	Control (n = 47)				Intervention (n = 52)				Difference at follow up (Intervention vs. Control)
	Baseline	Follow up	%	p	Baseline	Follow up	%	p	p
Weight (kg)	53.2 (11.9)	56.5 (13.1)	+8.5	0.001	53.4 (12.4)	56.6 (12.0)	+6.0	0.001	0.951
Standing height (m)	1.62 (0.07)	1.65 (0.07)	+1.9	0.001	1.63 (0.08)	1.66 (0.08)	+1.8	0.001	0.466
Body mass index (kg·m ⁻²)	20.0 (3.5)	20.4 (3.7)	+2.0	0.006	20.0 (3.5)	20.5 (3.3)	+2.5	0.001	0.895
Lean Mass (g)	31993 (4221)	32974 (5148)	+3.1	0.001	34699 (7110)	36993 (7591)	+6.6	0.001	0.002
Fat mass (g)	17245 (4984)	17219 (5337)	-0.2	0.913	17763 (7163)	17332 (7234)	-2.4	0.080	0.929
% Fat mass	25.5 (5.3)	24.9 (5.9)	-2.3	0.050	25.0 (7.3)	23.5 (7.7)	-6.0	0.001	0.323

Table 2
Eight-month change (mean \pm SD) in physical and lifestyle characteristics for boys (n = 46).

Parameter	Control (n = 24)				Intervention (n = 22)				Difference at follow up (Intervention vs. Control)
	Baseline	Follow up	%	p	Baseline	Follow up	%	p	p
Weight (kg)	58.6 (16.7)	63.0 (18.6)	+7.5	0.001	55.0 (13.8)	58.6 (13.1)	+6.5	0.001	0.398
Standing height (m)	1.640 (0.086)	1.687 (0.083)	+2.9	0.001	1.637 (0.098)	1.679 (0.100)	+2.6	0.001	0.801
Sitting height (m)	0.845 (0.049)	0.872 (0.047)	+3.2	0.001	0.841 (0.056)	0.862 (0.057)	+2.5	0.001	0.614
Body mass index (kg·m ⁻²)	20.5 (4.3)	20.8 (4.7)	+1.5	0.248	20.3 (3.6)	20.6 (3.2)	+1.5	0.213	0.810
Lean Mass (g)	33768 (5029)	35116 (6319)	+4.0	0.017	37410 (8418)	40741 (8588)	+8.9	0.001	0.016
Fat Mass (g)	16635 (6004)	16591 (6643)	-0.3	0.917	16292 (7473)	15201 (6962)	-6.7	0.010	0.493
Grip strength (kg)	27.2 (9.6)	31.8 (8.6)	+16.9	0.001	24.8 (6.3)	29.2 (7.7)	+17.7	0.001	0.384
Vertical jump (cm)	31.8 (8.9)	34.4 (8.2)	+8.2	0.010	32.7 (6.0)	35.6 (6.7)	+8.9	0.001	0.655
Physical activity score	3.55 (1.20)	3.27 (2.13)	-7.9	0.443	3.84 (1.50)	3.24 (1.60)	-15.6	0.057	0.275

Table 3
Eight-month change (mean \pm SD) in physical and lifestyle characteristics for girls (n = 53).

Parameter	Control (n = 23)				Intervention (n = 30)				Difference at follow up (Intervention vs. Control)
	Baseline	Follow up	%	p	Baseline	Follow up	%	p	p
Weight (kg)	50.0 (6.4)	52.6 (6.3)	+5.2	0.001	51.6 (10.5)	54.4 (10.5)	+5.4	0.001	0.496
Standing height (m)	1.602 (0.058)	1.621 (0.058)	+1.2	0.001	1.621 (0.060)	1.635 (0.055)	+0.8	0.001	0.428
Sitting height (m)	0.828 (0.030)	0.844 (0.026)	+1.9	0.001	0.852 (0.026)	0.862 (0.029)	+1.2	0.004	0.033
Body mass index (kg·m ⁻²)	19.6 (2.8)	20.0 (2.7)	+2.0	0.003	19.7 (3.5)	20.4 (3.5)	+3.6	0.001	0.688
Lean Mass (g)	30692 (2979)	31404 (3414)	+2.3	0.005	31870 (3906)	33083 (3477)	+3.8	0.001	0.084
Fat Mass (g)	17693 (4134)	17681 (4198)	-0.1	0.959	19299 (6638)	19556 (6973)	+1.3	0.325	0.230
Grip strength (kg)	20.3 (5.1)	23.4 (3.8)	+15.3	0.001	20.5 (4.4)	23.4 (3.9)	+14.1	0.001	0.982
Vertical jump (cm)	27.6 (7.4)	29.4 (6.0)	+6.5	0.077	29.7 (5.9)	30.5 (5.6)	+2.7	0.469	0.553
Physical activity score	3.43 (1.39)	4.42 (2.36)	+28.9	0.003	2.58 (1.73)	2.23 (1.63)	-13.6	0.332	0.209