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Fitness Changes in Adolescent Girls Following In-School Combined Aerobic and Resistance Exercise: Interaction With Birthweight

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Purpose: To assess the efficacy of a supervised in-school combined resistance and aerobic training program in adolescent girls and investigate whether responses differ according to birthweight. ***Methods:*** Participants (girls aged 13–17 y) were randomized either to an intervention replacing physical education (PE) classes with 2×60-minute training sessions per week ($n = 58$) or to a control group that continued to attend 2×60 minutes per week of curriculum PE ($n = 41$). We measured muscular fitness (handgrip, standing long jump, and sit-ups), cardiorespiratory fitness (20-m shuttle run), skinfolds, and lean body mass preintervention and postintervention and determined effect size (Hedge's g) differences between changes in these measures. We also compared changes within lower (<3000 g) and normal birthweight intervention and PE control subgroups. ***Results:*** The intervention group showed greater improvements in all the fitness measures and lean body mass ($g = 0.22$–0.48) and lower skinfold increases ($g = 0.41$) than PE controls. Within the intervention group, improvements in all fitness measures were larger in lower birthweight ($g = 0.53$–0.94) than in normal birthweight girls ($g = 0.02$–0.39). ***Conclusion:*** Replacing curriculum PE with supervised training improved muscular and cardiorespiratory fitness and body composition outcomes in adolescent females. Our findings suggest an enhanced adaptive response to training in participants with lower birthweight which warrants further investigation.

Keywords: cardiorespiratory, early life conditions, strength training, training adaptations, youth

Adolescence is a critical period for the adoption of healthy behaviors and limiting the accumulation of excess adiposity, factors that contribute to cardiometabolic risk profile (10). Physical inactivity is described as a global pandemic (20) with estimates that <20% of adolescents worldwide are sufficiently active (15). Declines in physical activity and in both key health-related components of fitness—cardiorespiratory and muscular—are also reported in youth internationally (32,34). Participation in physical activity is a key aspect of a healthy lifestyle, and aerobic and muscular fitness have independent and additive effects on cardiometabolic risk factors in youth (6,14,33) and on the risk of noncommunicable disease morbidity and mortality in adulthood (2). Physical activity guidelines for youth recommend both participation in moderate to vigorous aerobic activity and activities to strengthen muscles at least 2 times per week (35). Despite this, physical activity promotion in youth has traditionally given low priority to the development of muscle strength (13). This is of greater concern for youth in low–middle-income countries, such as Colombia, who show lower strength levels than their counterparts in high-income countries (6,28).

Potentially, strength deficits in low–middle-income countries' youth may relate to the higher prevalence of poorer nutritional conditions across the lifecycle, including prenatally (23). Evidence from cohort studies in both low–middle-income (3) and high-income countries (11) shows across all gestational ages that fetal growth restriction and low birthweight are associated with lower handgrip strength across the lifecycle, independent of confounding factors such as body size and physical activity levels (1). Muscle fiber number is determined at or soon after birth and is influenced

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by nutritional status during critical periods of early development (31). Lower muscle fiber number and alterations in muscle metabolism, differentiation, and growth signaling are reported in low birthweight young adults (16,18,19,29). These alterations potentially explain persistent lower strength values across the lifecycle in low birthweight individuals. The resistance training stimulus represents an obvious countermeasure to low muscle strength and mass induced by these early life influences (5). However, the only study comparing the response of normal versus intrauterine fetal growth restriction individuals to resistance training found attenuated muscular endurance adaptations in the growth restricted group but similar maximal strength improvements (4). In contrast, Madsen et al (24) reported increases in muscle mass following a cycling intervention in low but not in normal birthweight young adults. Therefore, it is unclear whether the response of muscle mass/function of intrauterine fetal growth restricted individuals to loading is impaired or not.

In the context of a low–middle-income country “strength deficit,” the present study had 2 objectives. The first was to compare the body composition and fitness changes following an in-school supervised exercise program, which included resistance exercise, with that of the curriculum physical education (PE) class. We hypothesized that supervised training would lead to greater gains in body composition and muscular and cardiorespiratory fitness characteristics than the standard curricular PE class. Scant, heterogeneous data are available regarding responses to chronic exercise in intrauterine growth restricted individuals. A further aim, therefore, was to explore, without predicting a direction, whether any potential changes in muscular fitness trends are modulated by birthweight status.

Methodology

Design

The study was a controlled intervention, which recruited children attending a mixed-sex state secondary school in the municipality of Girón, a suburb of the city of Bucaramanga, Colombia. The study was approved by the Bioethics Committee of the University of Santander and by the Ethics Committees of the FOSCAL International Clinic in Bucaramanga. The protocol was in accordance with the Declaration of Helsinki and the Colombian laws that govern clinical research in humans (resolution: 008430/1993 Ministry of Health). The study was part one of a clinical trial (NCT03779737) SIMAC: Fuerza muscular y capacidad aeróbica relación SImbiótica en escolares con bajo peso al nacer y riesgo metabólico (symbiotic relationship between muscular strength and aerobic capacity, metabolic risk, and low birthweight in schoolchildren).

All students aged 13–17 years were invited to participate but required written informed consent of both the student and their parent/guardian. However, potential participants were excluded if, based on an evaluation and basic physical assessment performed by a general practitioner and accompanied by the child’s parent/guardian, they were classified as below Tanner stage 3 (based on breast and pubic hair development), had any physical or mental disability that restricted their participation in an exercise training program involving muscle strengthening exercises and aerobic activities, or suffered from asthma. The parent/guardian or the child was free to withdraw from the study at any time.

Measurement Variables. Eligible volunteers accompanied by their parents completed a questionnaire on personal and family history and sociodemographic information. Anthropometric and physical fitness measurements were taken a week prior to and after the intervention. Parents/guardians were also asked to provide the participant’s hospital-issued certificate of birthweight.

We took anthropometric measurements of height using a mechanical stadiometer platform (Seca 274; Seca, Hamburg, Germany), and bodyweight and lean body mass were measured using bioelectrical impedance analysis (Tanita BC544; Tanita, Tokyo, Japan) of students wearing light clothing.

Subcutaneous skinfolds were measured with Harpenden calipers at 7 sites (bicipital, tricipital, subscapular, abdominal, iliac, thigh, and calf) according to the locations established by the International Society for the Advancement of Kinanthropometry, and the sum of skinfolds were calculated (16) and used as a marker of adiposity.

Three measures of muscular fitness were performed: handgrip (an index of upper body strength), standing long jump (lower body strength), and sit-up performance (muscular endurance). Muscular strength was measured with a Takei analog handgrip dynamometer (Takei T.K.K.5001 Grip A Dynamometer; Takei Scientific Instruments Co Ltd, Niigata-City, Japan). Pupils were given a brief demonstration and verbal instructions for the test, and if necessary, the dynamometer was adjusted according to the child’s hand size. The test was done in the standing position with the wrist in the neutral position and the elbow extended; children were given verbal encouragement to “squeeze as hard as possible” and apply maximal effort for at least 2 seconds. Two trials were allowed in each limb and the highest score recorded as peak grip strength (in kilograms). Two trials of standing long jump (distance in centimeters) were allowed with the best performance used in further analysis, and one attempt at performing the maximal number of sit-ups possible in 30 seconds.

Cardiorespiratory capacity was evaluated in groups of 6 using a maximum incremental indirect field test (21). In brief, the test requires participants to run “shuttles” back and forth between 2 lines 20 m apart in time with an audible “bleep” signal starting at an initial speed of 8.0 km/h, a speed which is a brisk walk or slow jog for most children. After 1 minute of shuttles at this pace, the audible signal changes to alert participants to the beginning of the next level and an increase in speed. Participants were encouraged to run for as long as possible but allowed to “drop out” of the test at any time if they felt unable to continue or to maintain the pace. They were also told that their test would be terminated if they failed to reach the line in time for the bleep on 2 consecutive shuttles. All tests were conducted in the school playground. After measurements were taken, the 153 eligible participants were randomly assigned to the intervention (n = 78) or to a control group (n = 75) that continued to attend curricular PE classes but were also measured at the end of the study period.

Intervention Group. Each training session consisted of a warm-up, an aerobic training, and a strength-training phase, followed by a cooldown. The 10- to 12-minute warm-up involved various multijoint mobility activities and exercises, such as squats, jumps, lateral hops, and planks as well as group movement games involving balls. The intensity of the warm-up was monitored using the modified Borg effort scale (0–10) (17) and did not exceed 6.

The 20- to 25-minute aerobic training component of the session involved various movement activities and games using basketballs, volleyball, soccer, steps, cones, and other equipment at an intensity monitored and progressed across the 22 weeks. During the initial sessions, the target was 60% to 65% of the estimated maximal heart rate (equivalent to 5–6 on the modified Borg scale with which sessions were monitored); the target was 80% to 85% of the estimated maximal heart rate (8–9 on the modified Borg scale) in the final weeks. During training sessions, a large poster of the modified Borg scale was put up to facilitate its use and support the maintenance of correct training intensities.

The approximately 20-minute strength training component centered on a 4-station multigym resistance machine to address the major muscle groups, interspersed with bodyweight resistance exercises. Participants exercised in pairs at each station and, upon completion of the prescribed number of sets, moved to the next station. Initial sessions were 3 to 15 repetitions to 40% to 50% of 1-repetition maximum, progressing to 4 sets of 10 repetitions at 75% to 85% of 1-repetition maximum in the final weeks. Following the resistance component, participants began a cooldown involving static stretching, emphasizing the main muscle groups that had been activated during the training session and generally performed in pairs. The exercises that were included in these sessions were pull down (prone and supine grip), leg press, chest press, shoulder abduction and flexion with dumbbell, standing triceps extension with cable, standing biceps cable curl, squats, lunges, and abdominal crunches.

PE Control Group. The PE control group continued participating in the twice a week, 1-hour curriculum PE class led by the school's PE teacher.

Statistical Analysis

Data analysis was performed using SPSS (Version 27.0; 2020, IBM Corp, IBM SPSS Statistics for Windows, Armonk, NY). The analysis of changes in the intervention versus control group (independent of birthweight) included participants who attended both assessments with complete data for each outcome measure. Table 1 shows unadjusted means (SD) for all outcome measures at baseline and follow-up. We used Cohen paired *d* to describe magnitude of within-group change for each outcome measure. This measure of standardized mean difference was calculated for the control and intervention groups using the difference in means divided by the pooled SDs (Equation 1).

$$d = \frac{m_1 - m_2}{SD_{pooled}}. \qquad (1)$$

Pairwise comparisons from noncontrolled interventions tend to produce larger effect size (ES) and inflated estimates of intervention efficacy compared with randomized controlled trials. To determine overall efficacy of the current intervention, we compared change in outcome measure by condition (intervention vs PE control group). Due to differences in group sizes, we calculated Hedge nonbiased estimate of ES (*g*) using weighted SDs. Hedge *g* is a measure of standardized mean difference that is broadly equivalent to Cohen *d* and also referred to as corrected *d* or adjusted ES.

$$g \cong d\left(1 - \frac{3}{4(n_1 + n_2) - 9}\right). \qquad (2)$$

To assess the potential influence of birthweight, we grouped girls reaching full gestational age and weighing > or <3000 g at birth into normal or lower birthweight groups. The lower birthweight group

Table 1 Baseline and Follow-Up Anthropometric and Physical Fitness Data in Intervention and Physical Education Control Groups, Within-Group Paired Effect Sizes, and Between-Condition Differences in Change

	Control (n = 41)		Paired effect size[b]	Intervention (n = 58)		Paired effect size[b]	Mean difference (95% CI)[c]	Effect size condition[d]
	Baseline	Follow-up		Baseline	Follow-up			
Age, y	13.2	13.2		13.3	13.3			
	0.7	0.7		1.1	1.1			
Stature, m	1.56	1.57		1.56	1.58			
	0.06	0.06		0.06	0.06			
Mass, kg	51.2	54.2		49.0	51.8			
	10.7	11.2		8.6	8.3			
BMI, kg/m^2	21.1	22.3		19.9	21.1			
	4.1	4.4		2.9	2.8			
Sum of 7 skinfolds,[a] mm	79.6	84.9	0.62	75.4	77.6	0.26	−2.2	0.41
	26.2	26.3		16.3	16.9		(−5.2 to 0.8)	
Lean body mass,[a] kg	35.3	35.7	0.29	34.2	35.4	0.54	0.58	0.33
	4.9	4.5		5.0	4.4		(−0.17 to 1.3)	
Handgrip,* kg	21.1	21.9	0.24	21.0	23.0	0.86	1.2	0.48
	3.4	3.5		3.7	3.3		(0.2 to 2.2)	
Standing long jump,* cm	120.7	118.6	−0.19	113.8	116.8	0.21	5.1	0.39
	23	25.6		16.5	17.1		(−0.1 to 10.4)	
Sit-ups,* n	31.5	28.6	−0.29	28.6	30.2	0.19	4.4	0.48
	8.8	8.8		7.3	7.6		(0.7 to 8.1)	
Shuttles,** n	44.2	42.7	−0.06	51.3	53.2	0.15	3.1	0.22
	14.4	20.7		16.3	22		(−2.8 to 9.0)	

Abbreviations: BMI, body mass index; CI, confidence interval. Note: All values are presented as unadjusted means and SDs.

[a] Effect size calculated from log-transformed values. [b] Effect size is Cohen *d*. [c] Mean difference (95% CI) $\Delta_{Control}$ versus $\Delta_{Intervention}$. [d] Effect size is Cohen *d* calculated between $\Delta_{Control}$ versus $\Delta_{Intervention}$.

*Muscular fitness. **Cardiorespiratory fitness.

included 14 girls with insufficient birthweight (2500–2999 g) and 9 with low birthweight (<2500 g) as defined by the World Health Organization. We created 4 condition × birthweight subgroups (intervention × lower birthweight, intervention × normal birthweight, PE control × lower birthweight, and PE control × normal birthweight). To reduce the number of contrasts required in this exploratory analysis, we calculated difference values (follow-up to baseline) as raw scores and as percentages. Mean percentage change was calculated for each subgroup (Figure 2). Because this grouping by birthweight created heterogeneous groups of unequal sizes, and mean and SDs differed by group at baseline, the homogenity of variance assumption was violated, pooling of SDs to calculate ES was not appropriate. We, therefore, used the SDs of the control group (unaffected by the intervention) instead of pooled values to calculate Glass delta as an unbiased measure of ES. For both analyses, we interpreted ESs as small ($d = 0.2–0.5$), moderate ($d = 0.5–0.8$), and large ($d \geq 0.8$).

Results

The intervention was offered to all children aged 13–17 years attending the mixed-sex state school. As very few boys volunteered, the analysis presented, therefore, pertains only to the female participants. The PE control group and intervention group attendance was 96% and 90% of the available classes and sessions, respectively. No injuries were reported in the intervention group during the 22-week study, and no students from the intervention group withdrew. Table 1 shows baseline descriptive data for the intervention and control groups (not accounting for birthweight). Only participants for whom a verified birthweight was obtained were included in analysis. This meant exclusion of 25 PE control and 17 intervention group participants. In addition, 9 PE control and 3 intervention participants who had moved to other schools and did not attend follow-up assessments were also excluded from the analysis. Baseline versus follow-up analysis, therefore, included 41 PE controls and 58 intervention participants.

Changes in Intervention and Control Groups and Differences in Magnitude of Change

Table 1 shows paired analysis of change between baseline and follow-up and the difference in change by condition, and Figure 1 shows percentage changes for each measure.

Sum of skinfolds increased by 7% in PE controls compared with 3% in the intervention group; the mean increase was –2.2 (–5.2 to 0.1) mm lower in the intervention group (ES = 0.41 difference between conditions). Lean body mass increased by <1% in PE controls and by 3% in the intervention group, the intervention gaining a mean of 0.6 (–0.2 to 1.3) kg more lean body mass than PE controls (ES = 0.33 difference between conditions). Handgrip increased by 9.5% in the intervention group compared with 3.8% in PE controls, a mean change that was 1.2 (0.2–2.3) kg greater in the intervention group than in PE controls (ES = 0.48 difference between conditions).

Standing long jump, sit-ups, and shuttle run all declined from baseline to follow-up in the control group. In contrast, there were small (3%–5%) increases in these measures in the intervention group and small but nontrivial ESs for condition (ES difference between conditions, all >0.2).

Changes in Lean Body Mass and Fitness Measures According to Intervention and Birthweight

Sixteen (26%) of the intervention group and 10 of the PE control group (24%) had lower birthweight. Table 2 shows means (SD) at baseline and follow-up by condition in girls with normal birthweight

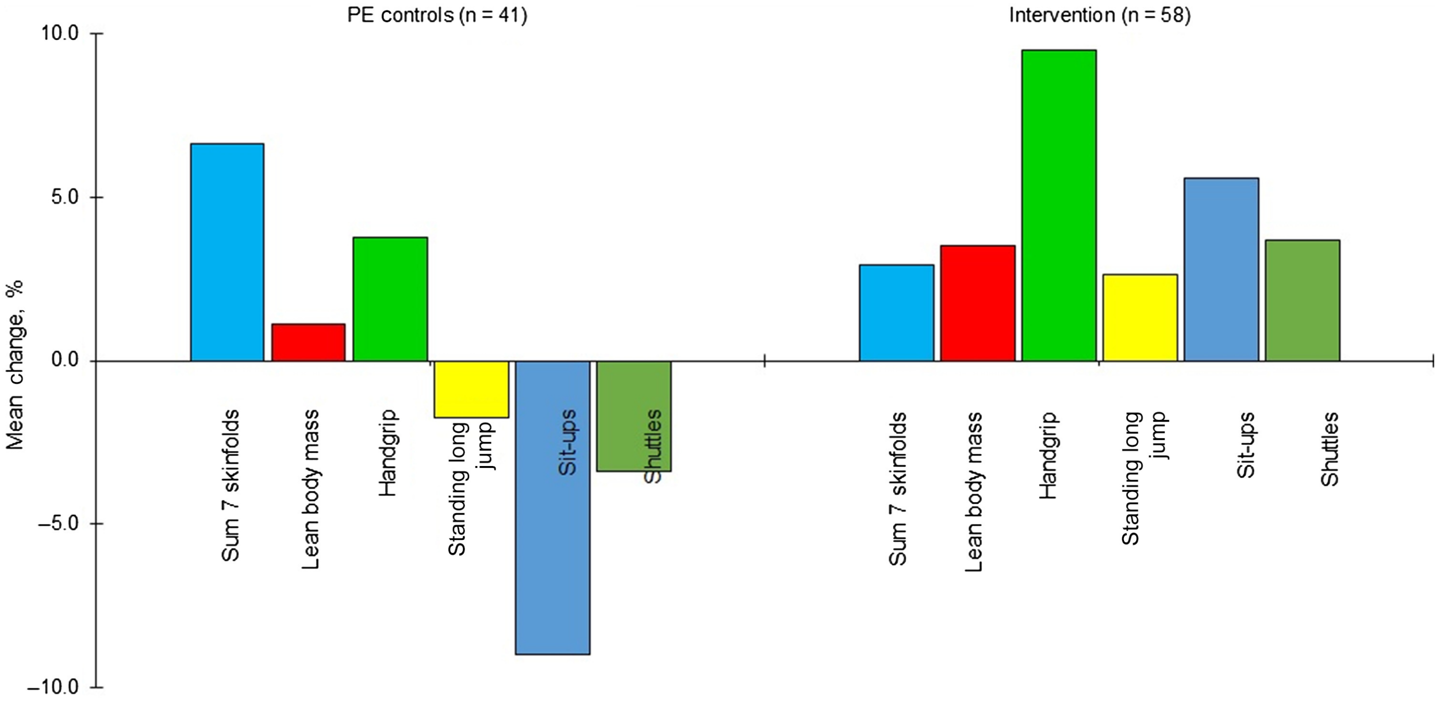

Figure 1 — Percentage change in measures of body composition and fitness by condition. PE indicates physical education.

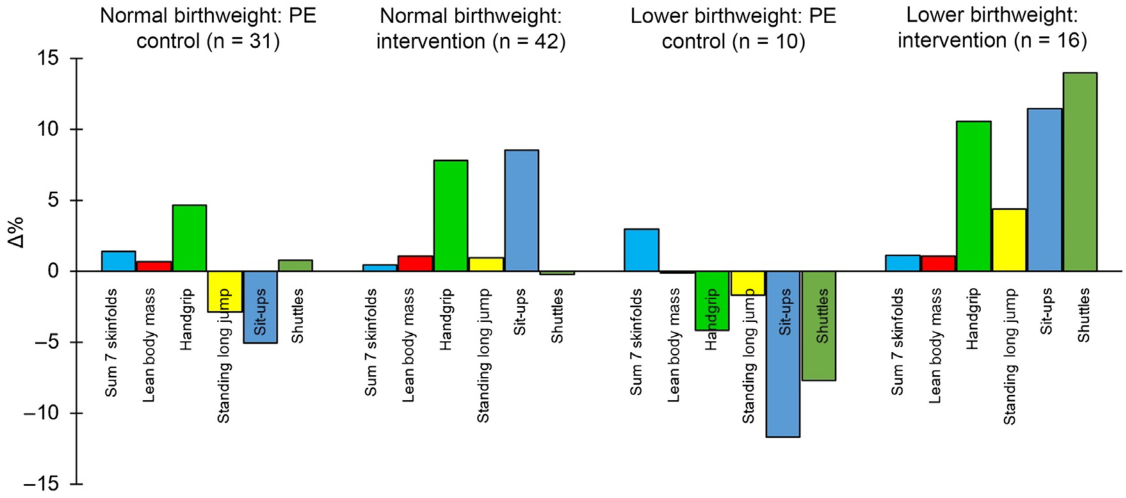

Figure 2 — Percentage change in measures of body composition and fitness by condition and birthweight category. PE indicates physical education.

Table 2 Baseline and Follow-Up Descriptive Anthropometric and Physical Fitness Data and Within-Group Paired Effect Sizes in Intervention and Physical Education Control in Normal and Lower Birthweight Groups

	Normal birthweight					Lower birthweight				
	PE control (n = 31)		Intervention (n = 42)			PE control (n = 10)		Intervention (n = 16)		
	Baseline	Follow-up	Baseline	Follow-up	Effect size condition[b]	Baseline	Follow-up	Baseline	Follow-up	Effect size condition[b]
Stature, m	1.56	1.58	1.57	1.58		1.55	1.56	1.55	1.57	
	0.07	0.07	0.06	0.05		0.05	0.04	0.06	0.06	
Mass, kg	51.5	54.6	50.2	52.8		50.2	53.0	45.9	49.0	
	10.5	11.1	9.0	8.7		11.9	11.9	7.0	6.4	
BMI, kg/m^2	21.1	22.4	20.3	21.4		20.9	22.1	19.1	20.4	
	4.1	4.4	2.9	2.9		4.4	4.5	2.8	2.6	
Sum 7 skinfolds, mm[a]	80.4	85.1	77.6	79.4	0.31	77.0	84.1	69.6	72.7	0.73
	24.7	26.4	16.0	17.3		31.8	27.4	16.3	15.2	
Lean body mass, kg[a]	35.0	35.8	34.3	35.6	0.18	34.6	34.4	33.4	34.4	0.61
	5.0	4.7	5.4	4.5		4.9	3.9	4.4	4.1	
Handgrip,* kg	21.0	22.2	21.6	23.3	0.32	21.5	20.9	19.6	22.1	0.92
	3.1	3.4	3.9	3.3		4.3	3.8	2.5	3.2	
Standing long jump,* cm	119.4	117.3	113.1	115.2	0.33	124.6	122.6	115.5	121.1	0.53
	23.1	27.4	15.4	17.5		23.7	19.6	19.5	15.6	
Sit-ups,* n	31.8	29.4	28.5	30.1	0.39	30.5	26.1	28.8	30.6	0.76
	9.6	9.7	7.6	6.5		5.9	5.2	6.8	10.2	
Shuttles,** n	42.3	43.6	52.7	52.4	–0.02	50.4	39.9	47.5	55.6	0.94
	14.9	22.1	16.6	20.5		11.3	16.3	15.6	25.9	

Abbreviations: BMI, body mass index. Note: All values are unadjusted means and SDs.

[a] Effect size calculated from log-transformed values. [b] Effect size is Hedge *g* (corrected effect size) to account for small sample size ($n < 20$) calculated from Δ_{Control} versus $\Delta_{\text{Intervention}}$.

*Muscular fitness. **Cardiorespiratory fitness.

(left panel) and lower birthweight (right panel), and Figure 1 shows percentage change. The ES for condition shown represents the difference change observed in the PE control and intervention groups and indicates the overall "efficacy" of the intervention with positive values indicating positive changes in each value.

Compared with normal birthweight girls, improvements were of greater magnitude and more consistent across outcomes in lower birthweight girls receiving the intervention.

Effect size differences by condition show that in the lower birthweight girls, the difference between intervention and PE control group changes in fitness and indicators of body composition were of larger magnitude and substantially so for lean body mass, lower birthweight, 0.61 versus normal birthweight, 0.18; for handgrip, lower birthweight, 0.92 versus normal birthweight, 0.32; and for shuttles, lower birthweight, 0.94 versus normal birthweight, 0.02. Although normal birthweight PE controls remained relatively stable, there was evidence of declines in handgrip, standing long jump, and particularly in sit-up and shuttles in the lower birthweight girls PE control condition.

Discussion

The present randomized controlled study compared the effects on body composition and fitness of a twice weekly concurrent resistance and aerobic training intervention with that of a PE class in Colombian high school girls during a 22-week period. In addition, we aimed to explore whether participants' birthweight influenced lean body mass and physical fitness changes in response to the exercise intervention. During the 22-week study period, height trends did not differ between the groups, an important finding given the anecdotal concerns that performing resistance exercise in this age group and in poorer socioeconomic conditions may attenuate longitudinal growth. Body composition changes were more favorable in the intervention group, who showed a larger increase in lean body mass and smaller increase in the sum of skinfolds than the PE control group. There was a large ES increase in handgrip, a small increase in standing long jump, and trivial increases in sit-up performance and shuttle number in the intervention group. In contrast, with the exception of a small increase in handgrip strength, we observed trivial (shuttle) or small declines across all measures of fitness in the PE controls. In addition to the improvement evidenced by the within-group comparison, the between-group contrasts suggest that the intervention had a small positive effect, which was of a meaningful magnitude across all fitness measures.

These findings demonstrate the efficacy of our twice weekly concurrent training intervention for improving body composition and promoting development of both muscular and cardiorespiratory fitness in adolescent girls. They also suggest that school PE provided an inadequate stimulus for the development of, or even the maintenance of, aspects of fitness in adolescent girls with mean declines of between 1.7% and 9% in shuttle number, sit-ups, and standing long jump observed during the study period in the PE control group. Conversely, mean improvements of 2.6% to 5.6% were achieved in these measures in the intervention group, and handgrip strength improvements were more than double those seen in PE controls. Despite the intensity of the aerobic program being difficult to control in the group setting with just the use of modified RPE, the program did lead to 3.7% (trivial magnitude) improvements in estimated cardiorespiratory fitness, but this was relative to a 3.5% decline in the PE group. Marta et al (25) also reported a 3.7% improvement in estimated cardiorespiratory fitness, which was statistically significant, in 45 girls aged 10–11.5 years during an 8-week twice weekly combined training intervention. Nonetheless, the difficulty of improving cardiorespiratory fitness in school-based physical activity interventions has been previously identified, with a systematic review finding significant effects on that aspect of fitness in girls in only one study (10).

Although unexpected, and of concern, a lack of improvement or declines in aspects of muscular fitness in a control group was also reported during an exercise intervention in schoolgirls in a state school in Brazil—standing long jump, sit-ups, and push-ups declined by 1%, 8%, and 8%, respectively, in 12 weeks (9). Data such as these question the adequacy of the muscular fitness stimulus within school PE programs in Latin America. Although muscular fitness is critical to sports performance, this has wider public health implications due to the associations between both components of fitness and cardiometabolic risk profile in youth (6,14,33) and to the burden of noncommunicable disease in adulthood (22). Furthermore, the intervention not only promoted greater improvements in lean body mass but also led to smaller increases in sum of skinfolds, suggestive of attenuated fat mass gain. This aligns with our previous findings following an after-school resistance training program in adolescents in a different state school in Colombia, also with a supervised intervention versus PE research design (7). The present intervention, conducted within school and during the same time period, demonstrated a more effective and efficient use of time in terms of achieving not only health-related fitness markers but also beneficial trends in body composition. The high level of interest and the near 100% attendance of adolescent girls was an encouraging and important aspect of the present study in the context of greater declines in physical activity during adolescence in girls than boys (12). In contrast, the boys preferred to continue with PE classes, which included organized sports.

Relative to youth in high-income countries, the present population has both a greater prevalence of lower birthweight and lower strength levels (8,27,a href="r28" ref-type="bibr">28). Intrauterine growth restriction, more common in low–middle-income countries, can induce epigenetic changes, which have persistent effects on various aspects of muscle morphology and metabolism (16,19,29). Furthermore, Jensen et al (19) suggested that the impaired signaling pathways mediating the muscle anabolic response to feeding that they observed in healthy lower birthweight adults may partly explain the persistence of muscle strength deficits reported in low birthweight individuals across the lifecycle (1,3,11,30). Given that exercise, and resistance training in particular, represents the most powerful nonpharmacological countermeasure to poor muscle strength and mass, it was of interest to determine whether birthweight and associated epigenetic background would also attenuate the response to the stimulus of training and limit muscular fitness adaptations. On the contrary, improvements in fitness (percentage wise) in the lower birthweight girls in response to the intervention were slightly (handgrip and sit-ups) or substantially larger (standing long jump and shuttles) than in the normal birthweight girls, suggesting an accentuated adaptive response to the intervention in terms of upper and lower body strength and cardiorespiratory fitness (shuttle run). Therefore, paradoxically, although low birthweight is associated with lower muscle strength in epidemiological studies, an exercise intervention that included a resistance and aerobic component produced increases in aspects of muscular fitness and aerobic fitness that were superior to those observed in their normal birthweight counterparts. Furthermore, based on the comparison between the magnitude of change in fitness by condition within birthweight groups (Table 2; ES by condition), the relative impact of the intervention was substantially greater in the lower birthweight girls. For example, the ES difference between change in handgrip strength in intervention versus PE groups in lower birthweight girls was more than double that observed in normal birthweight participants. Notably, although the lower birthweight participants did show larger responses to the intervention than those with normal birthweight, substantial declines in performance in the lower birthweight PE controls in all measures of fitness clearly contributed to this finding. Although the number of participants in this subsample analysis was relatively small, these data suggest that although lower birthweight girls were equally or more responsive in terms of muscular and cardiorespiratory fitness improvements when exposed to appropriate loading, they were also more vulnerable to an inadequate stimulus for muscle mass and fitness development. However, based on the first part of the study, the level of stimulus for these adaptations in curricular PE class may not provide an optimal stimulus for muscular fitness development. Therefore, particularly in communities with higher levels of poor maternal nutrition and a greater prevalence of low birthweight youth, who will be more vulnerable to sarcopenia and chronic disease in later life due to this early life "insult," greater attention should be given to ensuring exposure to adequate loading stimulus.

Intriguingly, an enhanced response of muscle to an exercise intervention has been previously reported in one of the 2 other studies evaluating the potential influence of intrauterine growth restriction on muscle mass/fitness outcomes. Madsen et al (24) found that following a 6-week unsupervised intervention, which prescribed 45 minutes of outdoor cycling, there were significant increases in fat-free mass and maximal aerobic capacity in low but not in normal birthweight young Indian men. In contrast, the only previous study to include resistance training when examining the interaction between intrauterine growth restriction and exercise training adaptations showed attenuated muscular endurance adaptations but similar maximal strength improvements in females with low ponderal index (like birthweight, an indicator of intrauterine growth restriction) (4). They dichotomized young adult females to low versus normal ponderal index and evaluated maximal strength, muscular endurance (assessed as the rate of decline in force during 3 × 1 min sets of dynamic contractions), pre and post an 8-week intervention which included aerobic interval cycling and 3 sets of lower body resistance training 3 times per week. There was no significant difference in the magnitude of improvement in handgrip and maximal isometric knee extension strength, but the intervention led to a smaller improvement in muscle endurance in the low ponderal index group compared with the normal ponderal index group. As aerobic capacity changes did not differ in low versus normal ponderal index women, this suggests a lower responsiveness specifically in terms of local muscle metabolic adaptations to the training.

Although clearly showing the superiority of a supervised in-school exercise intervention over standard PE of equal duration in enhancing fitness in adolescent girls, the present study has some weaknesses. First, the intervention involved the use of equipment that may not be available in many state school environments, and therefore, the results may not be widely applicable. Further studies should examine lower resource demanding interventions in this environment. Second, we failed to recruit an adequate number of boys to the study to include them in the analysis. However, given the greater decline in physical activity and fitness reported across adolescence in girls (12), their substantial interest and subsequent adherence to the program is itself an important finding. Another potential limitation was that 2 potential confounding factors that may have influenced these trends—nutritional habits and physical activity outside of the intervention and PE activities—were not evaluated. Indeed, it is suggested that strength training may enhance children's confidence in their physical abilities, resulting in greater involvement in sports and other physical activity (13), and has been shown to lead to increased spontaneous daily physical activity (26).

As the intervention was a combined aerobic and resistance training, any such positive secondary effects of the program on other physical activity could not be ascribed to one component of it. However, in future studies, it would be of interest to measure baseline nonprogrammed physical activity levels and changes in response to the programmed intervention.

Finally, our inclusion of only participants with verified birthweights resulted in a relatively small number of participants in each subgroup and potentially underpowered this subanalysis. Nonetheless, we did find statistically meaningful differences that warrant further investigation.

Further studies in adults are needed to determine the efficacy of the resistance training stimulus in low/lower birthweight adults in terms of strength adaptations. Although there should be continued emphasis on the improvement of maternal nutrition as a primary target for chronic disease reduction, a specific emphasis on delivery of the resistance training stimulus to low birthweight individuals could provide a "second chance" in terms of the normalization of muscle mass and quality and potentially translate into a countermeasure to their elevated vulnerability for diabetes and other noncommunicable diseases. Our findings that muscular and cardiorespiratory fitness adaptations are equal or greater following combined resistance and aerobic training, combined with poorer responses to curricular PE, suggest that in communities with a higher prevalence of poor early life nutrition, there should be a greater emphasis on strategies to promote and integrate an adequate exercise stimulus of this nature into school PE classes.

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