Effects of exercise intensity on cardiovascular fitness, total body composition, and visceral adiposity of obese adolescents[1–3]

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ABSTRACT

Background: Little is known about how the intensity of exercise influences cardiovascular fitness and body composition, especially in obese adolescents.

Objective: Our goal was to determine the effects of physical training intensity on the cardiovascular fitness, percentage of body fat (%BF), and visceral adipose tissue (VAT) of obese adolescents.

Design: Obese 13–16-y-olds ($n = 80$) were assigned to *1*) biweekly lifestyle education (LSE), *2*) LSE + moderate-intensity physical training, or *3*) LSE + high-intensity physical training. The intervention lasted 8 mo. Physical training was offered 5 d/wk, and the target energy expenditure for all subjects in physical training groups was 1047 kJ (250 kcal)/session. Cardiovascular fitness was measured with a multistage treadmill test, %BF with dual-energy X-ray absorptiometry, and VAT with magnetic resonance imaging.

Results: The increase in cardiovascular fitness in the high-intensity physical training group, but not in the moderate-intensity group, was significantly greater than that in the LSE alone group ($P = 0.009$); no other comparisons of the 3 groups were significant. Compared with the LSE alone group, a group composed of subjects in both physical training groups combined who attended training sessions ≥2 d/wk showed favorable changes in cardiovascular fitness ($P < 0.001$), %BF ($P = 0.001$), and VAT ($P = 0.029$). We found no evidence that the high-intensity physical training was more effective than the moderate-intensity physical training in enhancing body composition.

Conclusions: The cardiovascular fitness of obese adolescents was significantly improved by physical training, especially high-intensity physical training. The physical training also reduced both visceral and total-body adiposity, but there was no clear effect of the intensity of physical training. *Am J Clin Nutr* 2002;75:818–26.

KEY WORDS Exercise, visceral adiposity, intraabdominal fat, body composition, diet, physical training, obese adolescents, cardiovascular fitness

INTRODUCTION

Unfavorable cardiovascular risk profiles are found in youths with low levels of cardiovascular fitness, high percentages of body fat (%BF), and large amounts of truncal fat, especially visceral adipose tissue (VAT) (1–5). Therefore, as one aspect of the primary prevention of cardiovascular disease, it is important to develop and evaluate strategies that may favorably affect the fitness and body composition of juveniles. We reported previously that physical training alone, without dietary intervention, led to favorable changes in cardiovascular fitness, %BF, and VAT in obese 7–11-y-olds (6). To our knowledge, no information is yet available concerning the effect of physical training on VAT in adolescents. With respect to the cardiovascular fitness of juveniles, little is known about what intensity of exercise might be optimal. Two studies found somewhat better improvements in cardiovascular fitness when the physical training intensity was relatively high (7, 8).

With respect to body composition, few data are available on the effects of different amounts and intensities of exercise in persons of any age. An epidemiologic study of adults (9) found that those who engaged in greater amounts of free-living vigorous physical activity had lower general and central adiposity, even after control for total physical activity energy expenditure (EE). Within the framework of our intervention study of 7–11-y-olds, those children who spent the most weekly time engaged in vigorous physical activity during the 4-mo intervention period showed the greatest reductions in %BF (10). An intervention study of adults suggested that high-intensity physical training led to greater reductions in fatness than did moderate-intensity physical training (11), but a juvenile intervention study that controlled for EE during the physical training found skinfold fat to decline similarly in the low- and high-intensity physical training groups, even though the high-intensity physical training resulted in a clearer improvement in cardiovascular fitness (8).

There are several ways of obtaining "dose-response" information on the effects of exercise. Experimental designs in which subjects are randomly assigned to different amounts of exercise

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provide the clearest information about cause-effect relations. However, it is often difficult to control the interventions over the long periods of time required to see clear effects on fitness and body composition; thus, it is reasonable to also consider evidence from correlational analyses.

The primary hypothesis of this study was that, when compared with obese adolescents given lifestyle education (LSE) alone, obese adolescents who participated in physical training would show favorable changes in cardiovascular fitness, %BF, and VAT. A secondary hypothesis was that high-intensity physical training would be more effective than moderate-intensity physical training. Nonexperimental information about the intensity and volume of exercise was obtained in 2 ways. First, we explored the degree to which baseline variability among adolescents in fitness and body composition was explained by free-living moderate and vigorous physical activity and by diet. Second, we explored the degree to which changes in fitness or body composition were explained by individual differences in physical training process variables such as attendance at the physical training sessions, physical training heart rate, and estimated physical training EE. Another feature of the study involved the use of a submaximal rather than a maximal test as the primary index of change in cardiovascular fitness.

SUBJECTS AND METHODS

Subjects and study design

Obese 13–16-y-olds ($n = 80$) were recruited through flyers sent to parents of children who attended schools near our institute and through advertisements placed in community and hospital newspapers. Interested youths and parents were invited to the institute to view a videotape that illustrated the entire protocol and to sign informed consent documents in accordance with the procedures of our Human Assurance Committee. To be included, a youth needed to have a triceps skinfold thickness greater than the 85th percentile for sex, ethnicity, and age (12); to not be involved in any other weight control or exercise program; and to not be restricted as to physical activity. Note that the youths were not chosen to be representative of their ethnic or sex populations; consequently, we did not draw any conclusions about ethnic and sex differences in the variables measured. However, any differences that did occur were controlled for in the comparisons of experimental groups.

Youths underwent baseline testing and were randomly assigned, within sex and ethnicity groups, to 1 of 3 experimental groups. It was emphasized that, although only 2 of the 3 groups would participate in controlled physical activity at our facility, all groups would receive potentially valuable diet and physical activity information and that we were unsure which type of intervention would be most effective. One group was assigned to engage in biweekly lifestyle education (LSE) classes alone, the second group was assigned to LSE + moderate-intensity physical training, and the third group was assigned to LSE + high-intensity physical training.

The entire project was carried out in 2 waves, such that one-half of the subjects went through the project during its first year (cohort 1) and one-half during the second year (cohort 2); this allowed us to have class sizes small enough to carefully supervise the physical training. Most youths were transported to and from the physical training and LSE classes by our vans. Some youths lived outside the geographic area covered by our vans and agreed to provide their own transportation to participate in the study.

Full testing sessions were conducted at baseline and after 8 mo of the experimental period. Minitests of anthropometric indexes and free-living diet and physical activity were also conducted midway between the baseline and 8-mo test sessions. The youths were remunerated and encouraged to return for test sessions regardless of their degree of participation in the interventions so that they could be included in effectiveness (ie, intention-to-treat) analyses.

Measurement of body composition

Total body composition was measured by dual-energy X-ray absorptiometry (DXA) (QDR-1000, software version 6.0; Hologic Inc, Waltham, MA), which segments the body into the 3 compartments of fat mass, bone mineral content, and fat-free soft tissue, the last 2 of which constitute fat-free mass. %BF and bone density are also derived. Svendsen et al (13) showed that DXA values agree well with carcass analysis of pigs. We have found DXA to be reliable in children (14) and to be sensitive to changes elicited by physical training (15, 16). The whole-body scan time was 10–12 min and the radiation dose of $\approx$15 μSv ($\approx$1.5 mRem) was about the amount received in a cross-country airplane flight; therefore, our Human Assurance Committee approved the use of DXA in these healthy adolescents. Because nothing is known about the possible effects of even this small amount of radiation on a developing fetus, a urine sample was obtained from the girls to rule out pregnancy before the DXA measurement.

VAT and subcutaneous abdominal adipose tissue (SAAT) were determined in the Department of Radiology at the Medical College of Georgia with the use of a 1.5-T magnetic resonance imaging system (General Electric Medical Systems, Milwaukee) according to procedures previously described (17, 18). Spin-echo techniques were used to produce T1-weighted images showing good contrast between adipose and nonadipose tissues. Details of the magnetic resonance imaging acquisition were as follows: repetition time, 450 ms; echo time, 12 ms; field of view, 400–480 mm; matrix, 192 × 256; and number of excitations, 1. Respiratory compensation was used to reduce artifacts caused by respiratory motion. With subjects in the supine position, a series of five 1-cm thick transverse images was acquired beginning at the inferior border of the fifth lumbar vertebra and proceeding toward the head. A 2-mm gap between images was used to prevent crosstalk. Tissues superior to and inferior to the 5 slices were saturated to prevent blood flow in the aorta or inferior vena cava from appearing as high-intensity artifacts in the images. VAT and SAAT were quantified as adipose tissue within a region of interest bounded by the innermost aspect of the abdominal and oblique muscle walls and the posterior aspect of the vertebral body.

The multislice measurements are reported in cm^3; they were derived by multiplying the surface area for the individual images by the image width (1 cm) and then summing across the 5 images. To reduce interobserver variability, all images were analyzed by the same experienced observer. The intraclass correlation coefficients for VAT and SAAT from separate-day repeat analyses of the same scans exceeded 0.99. Because some adults experience claustrophobia when placed in the magnetic resonance imaging system, the youths viewed a brief videotape of the magnetic resonance imaging procedure at the time of the scheduling test sessions. The youths were then allowed to decline the magnetic resonance imaging measurement if they wished. None declined being scanned at baseline and 2 declined the scan at the postintervention assessment.

Body weight (in shorts and t-shirt) and height (without shoes) were measured with an electronic scale and a stadiometer, respectively, and converted to body mass index.

Measurement of cardiovascular fitness

The treadmill test began at a speed of 4.02 km/h (2.5 miles/h) and 0 grade for 2 min. The speed was then increased to 4.8 km/h (3 mph) for the next work rate and the grade was increased by 2% every 2 min from then on until the youth declined to continue despite encouragement. Oxygen consumption ($\dot{V}O_2$) was measured with a FITCO Metabolic Cart (Farmingdale, NY), and exercise heart rate was measured with a heart rate monitor (Polar Vantage XL; Polar, Port Washington, NY).

To conclude that the youth had achieved maximal $\dot{V}O_2$ ($\dot{V}O_2$max), at least one of the following criteria needed to be met: *1*) an oxygen plateau (ie, <2 mL·kg^{-1}·min^{-1} increase in $\dot{V}O_2$ with increasing work rate), *2*) a respiratory exchange ratio > 1.0, or *3*) heart rate > 200 beats/min. However, our primary index of cardiovascular fitness was submaximal in nature, ie, the $\dot{V}O_2$ at a heart rate of 170 beats/min ($\dot{V}O_2$-170).

We selected $\dot{V}O_2$-170 as our primary index of cardiovascular fitness for several reasons. First, in most studies, a substantial proportion of children typically fail to meet objective criteria for $\dot{V}O_2$max, despite encouragement to give a maximal effort, with the result that they cannot be included in analyses that include cardiovascular fitness, thereby reducing sample size. Second, ($\dot{V}O_2$max almost always occurs at the highest work rate attained; ie, it is really a performance test of maximal effort rather than an effort-independent physiologic index. Third, physical training seldom brings the children close to maximal levels of exertion; thus, a submaximal rather than a maximal index might be more sensitive to changes elicited by physical training.

As a result of these limitations in the $\dot{V}O_2$max test, we sought a different index of cardiovascular fitness. The heart rate at a given submaximal level of work or EE is a well-established submaximal and objective index of cardiovascular fitness in youths (19, pp. 68–72). By using all the treadmill workloads completed by each youth, we computed individual regression equations of $\dot{V}O_2$ versus heart rate for each youth. Then the $\dot{V}O_2$ (in L/min) corresponding to a heart rate of 170 beats/min was calculated for each youth on each of the tests and was expressed both in absolute terms (L/min) and per unit of body weight (mL·kg^{-1}·min^{-1}). We hypothesized that after training, the youths would be able to reach a higher $\dot{V}O_2$ (ie, a higher treadmill work rate) before their heart rate reached 170 beats/min.

Assessment of free-living physical activity and diet

Total daily physical activity was estimated from 7-d recalls (20) of the 7 d just before the interview: before the baseline testing, after 4 mo of the intervention period, and during the last week of the 8-mo intervention period. Thus, the 7-d recall included the physical activity associated with the physical training classes for the groups involved in physical training. Values from the hard and very hard categories of activity were summed to derive an index of vigorous physical activity.

Dietary data were obtained from 2-d recalls at the baseline, 4-mo, and 8-mo test sessions. Before the recall, each youth was given a form on which to record all food eaten for the 2 d before the interview; this information was used to assist the youth in remembering what he or she ate. We used the NUTRITION DATA SYSTEM (version 2.93) of the Nutrition Coordinating Center, which was established in 1974 at the University of Minnesota as a nutrition coding and resource center by the National Heart, Lung, and Blood Institute, and which provides support for a variety of research studies throughout the country (21). The data collection process is standardized by providing prompts that guide the interviewer through the collection of the 24-h recalls. For this study, we report data on total energy ingested and percentage of energy from each macronutrient.

Physical training

The physical training was offered 5 d/wk, except during the weeks when the group was scheduled for LSE on 1 d. Largely on the basis of our experiences in an earlier physical training study in which obese 7–11-y-olds expended an average of 971 kJ (232 kcal)/session during 4 mo of physical training (22), we decided to hold estimated EE constant at ≈1045 kJ (250 kcal)/session regardless of physical training group assignment. An exercise prescription was then developed for each subject on the basis of the data collected from the baseline treadmill test. First, the peak $\dot{V}O_2$ achieved by each youth on the treadmill test was identified, and the EE associated with 55–60% of peak $\dot{V}O_2$ (moderate-intensity physical training) or 75–80% of peak $\dot{V}O_2$ (high-intensity physical training) was determined. Because the high-intensity physical training group used more energy per minute, they were scheduled to exercise for fewer minutes per session than the moderate-intensity group. The number of minutes of exercise needed to expend 1045 kJ was estimated for each subject. Then, the heart rate and EE associated with that $\dot{V}O_2$ were determined for each youth.

During every physical training session, each youth wore a heart rate monitor (Polar Vantage XL; Polar). After each session, the minute-by-minute heart rate data were downloaded into a computer and displayed to the youth. The youths were encouraged to maintain their heart rates within 5 beats/min of their target heart rates.

Each exercise session provided some flexibility for the youths to select activities of their preference. Activities included exercise on machines (eg, treadmills, cycles, rowers, and steppers), aerobics, basketball, badminton, kickball, and aerobic slide. The instructors helped the youths to modify the exercise intensities to stay within their prescribed target heart rate zones. As an incentive, each youth was awarded points for maintenance of target heart rates that were redeemed for prizes. To encourage attendance, each subject was paid $1 for each physical training class attended.

Estimates of the achieved physical training EE were calculated separately for the first and second 4-mo components of the intervention. To estimate physical training EE during the first 4 mo of physical training, the average physical training heart rate for the first 4 mo was entered into the regression equation relating EE to heart rate derived from the preintervention treadmill test; the EE obtained was multiplied by the number of minutes that each youth actually exercised per session to derive the estimated physical training EE per session for the first 4 mo. This procedure was then repeated for the second 4-mo period with the use of the regression equation obtained on the postintervention treadmill test; the average of the first and second 4-mo periods of physical training was then calculated to derive an estimate of the physical training EE over the entire 8-mo period of physical training.

Lifestyle education

The 1-h LSE sessions were offered once every 2 wk for the 8 mo of the intervention; youths were paid $5 for each LSE class attended. Subjects from the 2 physical training groups were combined and the subjects in the LSE alone group were seen in separate sessions in alternating weeks to minimize contamination across the physical training and no physical training groups. The LSE included principles of learning and behavior modification, information about nutrition and physical activity, discussions of various aspects of the food consumption process, psychosocial factors related to obesity, and problem solving and coping skills. The LSE sessions were taught by a licensed clinical psychologist (CRL) who specializes in the treatment of eating disorders and obesity and has experience in providing LSE to children, adolescents, and adults.

Statistical analyses

Our subjects were not sampled to be representative of their particular sex and ethnicity subgroups, and cohort differences were probably due to our recruiting subjects from different schools and having different exercise leaders in the 2 cohorts. Therefore, we did not draw any inferences concerning differences by sex, ethnicity, or cohort. However, we did control for these factors in the analyses that evaluated the effects of other factors. For analyses that involved ethnicity (ie, black or white), the one Hispanic subject was omitted, but she was included in other analyses (eg, correlations).

An important issue in studies such as this one concerns how to express total body adiposity because analyses based on percentages can be misleading in comparisons of males and females or adults and children (23); however, as mentioned above, such comparisons were not an aim of this study. Thus, analysis of variance (ANOVA) provided a valid method for comparing the pre-post physical training differences in %BF. A different approach to the analysis of adiposity would be to analyze the fat mass of the 3 groups, with adjustment for fat-free mass at baseline and follow-up by analysis of covariance (ANCOVA). However, the calculation and comparison of adjusted means from the ANCOVA depends strongly on the regression of the dependent variable on the covariate having a constant slope across groups in the analysis; this assumption was not met in this sample. The most important reason we chose to use change in %BF as the primary dependent variable was conceptual rather than statistical; ie, the proportion of the body that is made up of fat is a biologically meaningful way to express total-body adiposity. Nonetheless, we also include information on the individual components of body composition to provide a more complete picture of the effect of the interventions.

A question may also be raised concerning whether it is appropriate to express $\dot{V}O_2$ per unit of body mass; this is a long-standing issue in the field of exercise physiology (24). As is true for adiposity, the use of ratios for expression of fitness may lead to spurious conclusions concerning age and sex differences, which was not the purpose of this study. Moreover, it can be argued that it is physiologically meaningful to express the concept of fitness as energy-generating capacity (ie, $\dot{V}O_2$) in a task involving transport of the body, per unit of mass that needs to be transported. Thus, a youth may improve fitness either by increasing the numerator or by decreasing the denominator. Although we favor this definition of cardiovascular fitness, we express the values both in absolute terms and per unit of body mass to accommodate both perspectives.

The statistical programs used for the analyses were SPSS-PC (version 10.0; SPSS Inc, Chicago) and SAS (version 8; SAS Institute Inc, Cary, NC). The dependent variables were checked for normality before the analyses, and appropriate transformations were applied when necessary.

The primary hypotheses were tested with univariate ANCOVA on the change in cardiovascular fitness, %BF, and VAT from baseline to 8 mo, followed by multiple comparisons with a Bonferroni correction. Both intention-to-treat and efficacy analyses were conducted. The intention-to-treat analyses used all subjects assigned to the experimental groups who returned for postintervention testing, regardless of their compliance with the prescribed regimens. The efficacy analyses used only subjects who met preset criteria for exposure to the interventions. The main criterion was attendance at the LSE and physical training sessions of ≥40%; for the physical training groups, this meant attending physical training sessions at least twice per week. To test the main hypothesis that the physical training would lead to favorable changes in $\dot{V}O_2$-170, %BF, and VAT, all youths who met the 40% attendance criterion were combined into one LSE + physical training group that was compared with the LSE alone group. To test the physical training intensity hypothesis, an additional criterion applied to the physical training groups was a mean heart rate during both the first and second 4-mo intervention periods within 10 beats/min of the prescribed heart rate range. The first model used the baseline value as a covariate, with sex, ethnicity, cohort, and interactions as fixed factors. Then nonsignificant factors were omitted from the model until a final model including only significant terms was obtained.

At baseline, we explored the extent to which demographic variables, diet, and physical activity explained variance in cardiovascular fitness, %BF, and VAT by using correlation and stepwise multiple regression by blocks. Because all the youths were in the obese category by virtue of being above the 85th percentile in triceps skinfold thickness, the magnitude of associations was probably attenuated; however, the youths varied in DXA-derived %BF from 26–63%BF, allowing us to determine the nature of the associations at the upper end of the adiposity spectrum.

The significance level required for entry into the regression models was 0.15, and the significance level required to remain in the model was 0.05. Two-factor interactions were calculated for each pair of main effects retained in the model and the stepwise procedure was rerun to identify which of these would be added to the model, with the use of the same criteria as for the main effects. For each successive block, the variables that were included in previous blocks were forced into the model. Any main effect term that was a component of a significant interaction term was retained in the model.

When we explored correlates of individual variability in response to the interventions, we found that a relatively small number of subjects had complete data for all relevant change scores, suggesting that stepwise regressions would be unstable. Therefore, we simply examined bivariate and multiple correlates of the change scores. First, we examined correlates of change for all the subjects in all groups for whom a baseline-to-postintervention difference score was available. Then we analyzed the physical training subjects alone to see whether individual differences in the changes in fitness and adiposity could be explained by physical training process variables such as attendance at the physical training sessions, physical training heart rate, and physical training EE.

RESULTS

Baseline characteristics and relations

The characteristics of the subjects who did or did not achieve $\dot{V}O_2$max at baseline are shown in **Table 1**. As expected, the peak

TABLE 1
Characteristics of the subjects who did or did not achieve maximal oxygen consumption ($\dot{V}O_2$max) at baseline[1]

	Achieved $\dot{V}O_2$max (n = 66)	Did not achieve $\dot{V}O_2$max (n = 14)
Age (y)	14.9 ± 0.1	14.5 ± 0.3
Height (cm)	165 ± 0.8	165 ± 2.8
Weight (kg)	92.3 ± 2.2	104.9 ± 5.9[2]
%BF (%)[3]	44.1 ± 0.9	46.5 ± 1.4
$\dot{V}O_2$-170 ($mL \cdot kg^{-1} \cdot min^{-1}$)	19.8 ± 0.6	18.9 ± 0.9
Peak $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	24.1 ± 0.7	18.9 ± 0.8[4]
Peak heart rate (beats/min)	191 ± 1.4	168 ± 3.1[4]
Peak RER	1.07 ± 0.01	0.95 ± 0.01[4]

[1] $\bar{x}$ ± SEM. %BF, percentage of body fat; $\dot{V}O_2$-170, oxygen consumption at a heart rate of 170 beats/min; RER, respiratory exchange ratio.

[2,4] Significantly different from those who achieved $\dot{V}O_2$max (independent *t* test): [2] $P = 0.026$, [4] $P \leq 0.001$.

[3] n = 65 and 13, respectively.

values for $\dot{V}O_2$, heart rate, and the respiratory exchange ratio were significantly lower in the group that did not achieve $\dot{V}O_2$max. The subjects who did not achieve $\dot{V}O_2$max were also significantly heavier. In the 66 subjects who achieved $\dot{V}O_2$max, $\dot{V}O_2$-170 was highly correlated with $\dot{V}O_2$max ($r = 0.88$, $P < 0.001$). To retain the maximal number of subjects in analyses involving cardiovascular fitness, $\dot{V}O_2$-170 was used as the index of cardiovascular fitness in subsequent baseline analyses.

The baseline characteristics of the subjects, stratified by ethnicity and sex, are shown in **Table 2**. There were no significant differences among the randomly assigned experimental groups, and there were no significant ethnicity-by-sex interactions. With respect to the 3 main outcome variables: *1*) the whites and males had significantly higher cardiovascular fitness ($\dot{V}O_2$-170) than did the blacks and girls, respectively; *2*) there were no significant ethnicity or sex differences in %BF; and *3*) VAT was significantly higher in the whites than in the blacks.

Cardiovascular fitness was inversely correlated with %BF ($r = -0.622$, $P < 0.001$), but was not significantly correlated with VAT ($r = -0.171$, $P = 0.133$). %BF and VAT were significantly, but modestly, correlated ($r = 0.333$, $P = 0.003$), showing that to a large degree they represent somewhat different aspects of adiposity in obese youths. With respect to correlates of cardiovascular fitness and adiposity at baseline, cardiovascular fitness was significantly correlated with free-living vigorous physical activity ($r = 0.400$, $P < 0.001$) but not with any of the other physical activity or dietary variables; however, the inverse correlation with dietary protein was nearly significant ($r = -0.210$, $P = 0.063$). The final regression model for cardiovascular fitness included ethnicity ($P = 0.012$), sex ($P = 0.0001$), dietary protein ($P = 0.005$), and vigorous physical activity ($P = 0.016$); the final R^2 was 0.431.

%BF was inversely correlated with vigorous physical activity ($r = -0.335$, $P = 0.003$) and dietary carbohydrate ($r = -0.256$, $P = 0.024$) and was positively correlated with dietary protein ($r = 0.269$, $P = 0.017$). The final model included dietary protein ($P = 0.012$) and vigorous physical activity ($P = 0.002$); the final R^2 was 0.190.

VAT was significantly correlated with age ($r = 0.295$, $P = 0.008$) and was significantly higher in cohort 1 than in

TABLE 2
Baseline characteristics of the subjects by ethnicity and sex[1]

	White boys (n = 10)	White girls (n = 15)	Black boys (n = 16)	Black girls (n = 39)	Significant differences[2]
Age (y)	14.5 ± 0.4	15.3 ± 0.3	14.1 ± 0.3	15.2 ± 0.2	Girls > boys
Weight (kg)	95.2 ± 8.7	88.5 ± 4.6	100.2 ± 4.4	94.8 ± 2.9	NS
Height (cm)	168 ± 3	163 ± 2	169 ± 2	164 ± 1	Boys > girls
VAT (cm^3)	394 ± 37	355 ± 39	279 ± 27	264 ± 18	Whites > blacks
SAAT (cm^3)	2356 ± 292	2558 ± 180	2608 ± 219	2633 ± 129	NS
%BF (%)	40.7 ± 2.2	45.8 ± 1.5	43.9 ± 2.3	45.2 ± 0.9	NS
$\dot{V}O_2$-170					
($mL \cdot kg^{-1} \cdot min^{-1}$)	25.0 ± 1.8	20.8 ± 0.8	20.5 ± 0.8	17.5 ± 0.5	Whites > blacks, boys > girls
(L/min)	2.34 ± 0.23	1.82 ± 0.08	2.04 ± 0.11	1.63 ± 0.06	Whites > blacks, boys > girls
VO_2max[3]					
($mL \cdot kg^{-1} \cdot min^{-1}$)	31.0 ± 2.7	24.7 ± 1.0	25.6 ± 1.4	21.5 ± 0.7	Whites > blacks, boys > girls
(L/min)	2.84 ± 0.31	2.19 ± 0.09	2.50 ± 0.11	1.97 ± 0.06	Whites > blacks, boys > girls
Fat mass (kg)	36.6 ± 3.9[2]	40.6 ± 2.8	44.5 ± 3.8	42.6 ± 1.8	NS
Fat-free soft tissue (kg)	50.3 ± 4.2[2]	44.8 ± 2.1	52.8 ± 2.5	47.7 ± 1.1	Boys > girls
BMC (kg)	2.2 ± 0.2[1]	2.3 ± 0.1	2.5 ± 0.1	2.7 ± 0.1	Blacks > whites
BMD (g/cm^2)	1.03 ± 0.04[2]	1.07 ± 0.02	1.08 ± 0.03	1.20 ± 0.01	Blacks > whites, girls > boys
Moderate PA (min/d)	42.9 ± 13.7	27.4 ± 8.2	23.4 ± 4.2	34.2 ± 6.9	NS
Vigorous PA (min/d)	47.6 ± 9.5	31.9 ± 11.3	21.4 ± 8.5	13.5 ± 3.1	Whites > blacks
Dietary energy (kJ/d)	6472 ± 573	6005 ± 732	7396 ± 696	5568 ± 330	NS
Dietary protein (% of energy)	16.1 ± 0.7	13.1 ± 1.0	14.6 ± 0.9	14.7 ± 0.7	NS
Dietary carbohydrate (% of energy)	52.1 ± 2.5	57.7 ± 3.1	52.3 ± 2.5	52.0 ± 1.6	NS
Dietary fat (% of energy)	32.4 ± 2.5	31.0 ± 2.6	34.1 ± 1.8	34.2 ± 1.3	NS

[1] $\bar{x}$ ± SEM. VAT, visceral adipose tissue; SAAT, subcutaneous abdominal adipose tissue; %BF, percentage of body fat; $\dot{V}O_2$-170, oxygen consumption at a heart rate of 170 beats/min; $\dot{V}O_2$max, maximal oxygen consumption; BMC, bone mineral content; BMD, bone mineral density; PA, physical activity.

[2] Because there were no significant ethnicity-by-sex interactions, comparisons are shown for the main effects of sex and ethnicity (the 1 Hispanic youth was excluded) as determined by ANOVA.

[3] $\dot{V}O_2$max was achieved by 66 subjects.

TABLE 3
Exercise prescriptions, achieved heart rate and energy expenditure (EE), and attendance for all subjects who returned for postintervention testing[1]

	Moderate-intensity physical training ($n = 21$)	High-intensity physical training ($n = 21$)
Prescribed $\dot{V}O_2$ (% of peak)	55–60	75–80
Prescribed heart rate (beats/min)	137 (120–162)	167 (146–202)
Prescribed session duration (min)	43 (28–61)	29 (17–45)
Achieved heart rate (beats/min)	138 (124–163)	154 (132–177)[2]
Achieved estimated EE (kJ)[3]	1049 (761–1676)	991 (723–1241)
Attendance (%)[3]	51 (5–92)	56 (16–83)

[1] Range only or $\bar{x}$ with range in parentheses. $\dot{V}O_2$, oxygen consumption.

[2] Significantly different from the moderate-intensity physical training group, $P < 0.001$ (ANOVA adjusted for sex, ethnicity, and cohort).

[3] There was no significant difference between groups.

cohort 2 ($P = 0.022$). The final model for VAT included cohort ($P = 0.013$), ethnicity ($P < 0.001$), age ($P = 0.020$), and dietary carbohydrate ($P = 0.035$; higher VAT was associated with lower carbohydrate intake, bivariate $r = -0.163$, $P = 0.153$). The final R^2 was 0.314.

Effects of the interventions: intention-to-treat analyses

The prescribed intensities and durations of exercise, the heart rates actually attained during the physical training, the corresponding estimates of energy expended during the physical training, and the attendance at the physical training sessions are shown in **Table 3**. The average attendance values of the 2 physical training groups were not significantly different. For the moderate-intensity group, the prescribed and attained heart rates were not significantly different (137 and 138 beats/min, respectively). However, we had difficulty in keeping those assigned to the high-intensity group in their target zones, and the actual mean heart rate achieved (154 beats/min) was significantly lower than the prescribed mean heart rate (167 beats/min; $P < 0.001$). Nevertheless, the attained mean heart rate of the high-intensity group was significantly higher than that of the moderate-intensity group, whereas the estimated EEs did not differ significantly. Because the intensity distinction between groups was not as great as planned, our ability to test the physical training intensity hypothesis was correspondingly weakened.

The change in $\dot{V}O_2$-170 from baseline to 8 mo in the 3 groups is shown in **Figure 1**. We obtained a $\dot{V}O_2$-170 value for only 57 of 61 subjects who returned for postintervention testing because of technical problems. The mean changes in $\dot{V}O_2$-170 for the 3 groups were significantly different ($P < 0.001$). The post hoc tests showed that the LSE + high-intensity physical training group improved significantly more than did the LSE alone group; the moderate-intensity group was not significantly different from either of the other groups. Only 38 subjects achieved the physiologic criteria for $\dot{V}O_2$max on both the baseline and postintervention tests, and the ANOVA did not indicate a significant difference between groups.

The intention-to-treat analyses of %BF and VAT showed no significant differences between the 3 groups (data not shown). Thus, we proceeded to conduct efficacy analyses by using only subjects who met the criteria for exposure to the physical training.

Effects of the interventions: efficacy analyses

First we tested the primary hypothesis that those youths who participated in LSE + physical training would show more favorable changes in cardiovascular fitness and body composition than would those who engaged in LSE alone. Thus, we formed a group comprising those in both physical training groups who attended ≥2 d/wk in both the first and second 4-mo periods of the intervention and compared this group with the LSE alone subjects who attended ≥40% of the LSE sessions. As shown in **Table 4**, the hypothesis was supported for the 3 primary outcome variables.

The LSE + physical training group improved more than did the LSE alone group in both $\dot{V}O_2$-170 and $\dot{V}O_2$max, regardless of whether these variables were expressed per unit of weight. The P values for $\dot{V}O_2$max were somewhat higher than those for $\dot{V}O_2$-170, perhaps partly because fewer subjects were available for the $\dot{V}O_2$max comparisons and the mean differences between groups were somewhat less than for $\dot{V}O_2$-170.

VAT declined significantly more in the LSE + physical training group. Although the group difference in SAAT was in the hypothesized direction, it was not significant. %BF in the LSE + physical training group declined, whereas it increased slightly in the LSE alone group; this group difference was significant.

Also shown in Table 4 are the changes in each of the components of total body composition. The group difference in fat mass was nearly significant ($P = 0.072$); the changes in fat-free soft tissue were not significantly different between groups. The increases in bone mineral content and bone density were significantly greater in the LSE + physical training group. With respect to diet, total energy intake increased significantly more in the LSE + physical training group, whereas none of the group differences in changes in intakes of the individual macronutrients were significant.

To test the hypothesis that the high-intensity physical training would be more efficacious than the moderate-intensity physical training, we initially set 2 criteria for adequate exposure to the

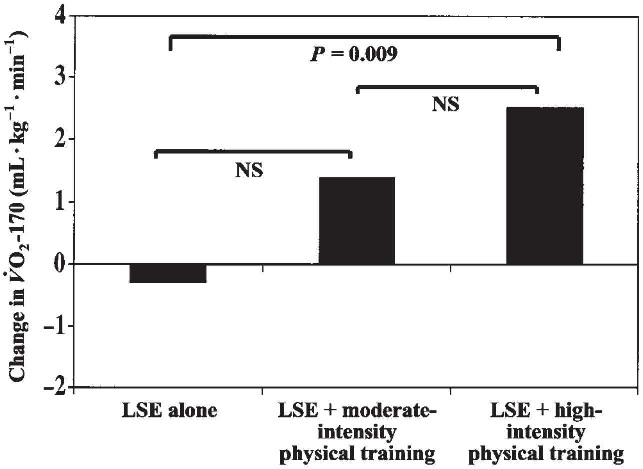

FIGURE 1. Changes in cardiovascular fitness over the 8-mo intervention period in the subjects randomly assigned to lifestyle education (LSE) alone ($n = 17$; SEM = 0.66), LSE + moderate-intensity physical training ($n = 21$; SEM = 0.60), or LSE + high-intensity physical training ($n = 19$; SEM = 0.63), regardless of their degree of compliance with the prescribed regimens. Values shown are least-square means adjusted for baseline value, cohort, ethnicity, and sex, as appropriate. $\dot{V}O_2$-170, oxygen consumption at a heart rate of 170 beats/min.

TABLE 4

Change from baseline to 8 mo in the lifestyle education (LSE) alone group compared with both LSE + physical training groups combined[1]

	LSE alone (n = 17–19)	LSE + physical training (n = 20–22)
$\dot{V}O_2$-170		
(mL · kg^{-1} · min^{-1})	−0.33 ± 0.51	3.56 ± 0.58[2]
(L/min)	−0.037 ± 0.042	0.337 ± 0.047[2]
$\dot{V}O_2$max[3]		
(mL · kg^{-1} · min^{-1})	−0.40 ± 0.71	1.72 ± 0.60[4]
(L/min)	0.004 ± 0.082	0.230 ± 0.069[4]
VAT (cm^3)	−11.0 ± 10.0	−42.0 ± 9.3[4]
SAAT (cm^3)	40.4 ± 60.4	−69.7 ± 55.9
%BF (%)	0.19 ± 0.62	−3.57 ± 0.80[2]
Fat mass (kg)	1.62 ± 0.92	−0.73 ± 0.87
Fat-free soft tissue (kg)	1.80 ± 0.55	1.69 ± 0.52
BMC (g)	109 ± 20	167 ± 18[4]
BMD (g/cm^3)	0.041 ± 0.006	0.047 ± 0.007[4]
Moderate PA (min/d)	3.63 ± 4.79	−0.87 ± 4.43
Vigorous PA (min/d)	−3.63 ± 6.10	6.40 ± 5.66
Dietary energy (kJ/d)	84 ± 397	407 ± 369[5]
Dietary protein (% of energy)	0.03 ± 0.88	0.98 ± 0.81
Dietary carbohydrate (% of energy)	0.18 ± 1.70	−1.42 ± 1.58
Dietary fat (% of energy)	−0.49 ± 1.42	1.43 ± 1.33

[1] Least-squares mean ± SEM adjusted for baseline value, cohort, ethnicity, and sex, as appropriate. All subjects attended ≥40% of the LSE and physical training sessions. $\dot{V}O_2$-170, oxygen consumption at a heart rate of 170 beats/min; $\dot{V}O_2$max, maximal oxygen consumption; VAT, visceral adipose tissue; SAAT, subcutaneous abdominal adipose tissue; %BF, percentage of body fat; BMC, bone mineral content; BMD, bone mineral density; PA, physical activity.

[2,4,5] Significantly different from LSE alone group (ANCOVA): [2] $P \leq 0.001$, [4] $P < 0.05$, [5] $P < 0.01$.

[3] $\dot{V}O_2$max was achieved by only 10 and 14 subjects, respectively.

specific doses of physical training: attendance of ≥40% and heart rate within 10 beats/min of the prescribed moderate- or high-intensity heart rate zones. However, because of the difficulty we had in keeping subjects in their target zones, the number of subjects remaining in the physical training groups fell to 9 and 8, compromising our ability to test the intensity hypothesis. No evidence was provided that the high-intensity physical training was more efficacious than the moderate-intensity physical training in enhancing cardiovascular fitness or body composition (data not shown).

Correlates of change

In the analysis that included all subjects who returned for postintervention testing (n = 57), %BF increased more in the girls than in the boys, as would be expected in adolescents (data not shown). There were significant intercorrelations of change scores for the 3 main outcome variables (**Table 5**). None of the changes in free-living diet or physical activity were significantly correlated with changes in the outcome variables.

In the analysis that included only the subjects who engaged in physical training (n = 40), the change in cardiovascular fitness was significantly correlated with all 3 physical training process variables; the multiple correlation for all 3 independent variables combined was R = 0.562 (Table 5). The bivariate correlations between change in %BF and the physical training process variables were not significant. However, they were all in the expected direction and the multiple correlation was significant, permitting the conclusion that those youths who had a greater physical training "dose," as represented by the combination of heart rate, estimated EE, and attendance, tended to show the most favorable change in %BF (R = 0.365). Change in VAT was not significantly correlated with any of the process variables.

DISCUSSION

The present study showed that obese 13–16-y-olds who participated in ≥2 d/wk of afterschool exercise plus an LSE program over an 8-mo period showed more favorable changes in cardiovascular fitness, %BF, and VAT than did youths who participated in the LSE alone. The favorable effect on visceral adiposity is noteworthy because this fat depot was found to be the most powerful of the adiposity measures for explaining variance in lipid-lipoprotein measures in these subjects at baseline (5) and because so little information is available concerning how to modify this fat depot. No significant group differences were found in free-living physical activity, and the only significant difference in dietary change was a slightly greater increase in energy intake in the LSE + physical training group. Thus, the favorable increases in fitness and decreases in adiposity can be attributed to the physical training program itself.

The positive effects of the physical training on visceral adiposity in these adolescents complement the results of a study of strength training in prepubertal girls (25) and our previous study of aerobic training in 7–11-y-olds (6). These findings suggest that interventions that combine LSE and exercise may be especially likely to produce favorable changes in the VAT of growing youths. Because the LSE alone group received counseling on diet and physical activity, they cannot be considered a true nonintervention control group. Our previous physical training study did include a nonintervention control group, in whom VAT increased, as would be expected as youths mature; in that study, the 4-mo physical training program attenuated the age-related increase in VAT. In the current study, the 8-mo LSE alone intervention led to a slight decrease in VAT whereas the LSE + physical training intervention led to a greater reduction. This suggests that a combination of LSE and exercise is especially likely to produce favorable changes in VAT in growing youths.

With respect to how the components of body composition responded to the physical training, bone mineral content and

TABLE 5

Bivariate correlations between change (Δ) in the outcome variables for all subjects who completed postintervention testing (n = 57), the bivariate correlations between the physical training process variables and change in the outcome variables for those who engaged in physical training (n = 40), and the multiple correlations between the physical training process variables taken together and the outcome variables[1]

	$\Delta\dot{V}O_2$-170	Δ%BF	ΔVAT
$\Delta\dot{V}O_2$-170		−0.520[2]	−0.325[3]
Δ%BF	—		0.349[2]
Process variables			
Attendance	0.316[3]	−0.211	−0.043
Heart rate	0.424[2]	−0.277	−0.032
EE	0.372[3]	−0.232	−0.243
Multiple R	0.562[2]	0.365[3]	0.245

[1] $\dot{V}O_2$-170, oxygen consumption at a heart rate of 170 beats/min; %BF, percentage of body fat; VAT, visceral adipose tissue; EE, energy expenditure.

[2] $P < 0.01$.

[3] $P < 0.05$.

bone mineral density increased significantly more in the LSE + physical training group, suggesting that exercise has a favorable effect on bone development in growing youths. This is consistent with the findings of our study of 7–11-y-olds (16).

We found that some of the 13–16-y-olds were more resistant to participation in the intervention than the 7–11-y-olds of similar ethnic and sex composition whom we studied previously (22). In fact, several of the youths in cohort 2 met diagnostic criteria for oppositional defiant disorder (26); they were resistant to active participation and also interfered with the activities of the other youths. We suggest that studies of adolescents use a compliance run-in period to identify and remove such youths early in the project.

With respect to cardiovascular fitness, the intention-to-treat analysis found that the change in $\dot{V}O_2$-170 in the high-intensity group was significantly greater than that in the LSE alone group, whereas the change in the moderate-intensity group did not differ significantly from that in the LSE alone group. Thus, if we had used only moderate-intensity physical training, the intention-to-treat analysis might have failed to find that the physical training enhanced cardiovascular fitness.

At baseline, those youths who did not achieve $\dot{V}O_2$max were heavier than those who did; thus, studies that use $\dot{V}O_2$max as the index of cardiovascular fitness may bias the sample in favor of lighter youths. For example, a study found that youths with higher baseline $\dot{V}O_2$max values had lesser increases in adiposity over the next 3–5 y (27); in that study, 17% of the youths did not achieve $\dot{V}O_2$max and were excluded from the analysis. There is no way to tell whether the results would have differed if all the subjects had been included. Anecdotal reports from many subjects whom we have tested indicate that putting forth a maximal effort is the most aversive task the youths need to perform in our testing protocols and that such effort is a barrier to their returning for follow-up tests. Taken together, these factors support the use of a submaximal index such as $\dot{V}O_2$-170 when assessing cardiovascular fitness, especially in obese youths.

The correlational analyses of baseline and change scores supplemented the experimental results. At baseline, cardiovascular fitness was significantly correlated with time spent in free-living vigorous physical activity but not with moderate physical activity; this is consistent with the experimental finding that the high-intensity physical training, but not the moderate-intensity physical training, produced significant changes in cardiovascular fitness. It is also consistent with the results of other studies in children that compared moderate- and high-intensity physical training (7, 8).

The regression analysis showed that baseline %BF was associated with low levels of vigorous physical activity, low dietary carbohydrate intake, and high dietary protein intake. The association of %BF with vigorous, but not moderate, physical activity is consistent with the results of a study in children showing that aerobic fitness, but not EE in general activity, predicted lesser gains in adiposity over the next 3–5 y (27). Because vigorous physical activity is likely to lead to increases in fitness, it is possible that such exercise is desirable over the long term for achievement of a healthy body composition. To provide clear experimental tests of the intensity hypothesis may require studies in which the physical training is carried out over longer periods of time (eg, measured in years rather than months) and in which the physical training sessions are longer (eg, measured in hours rather than minutes per day).

Baseline VAT was also higher in the youths with a relatively small carbohydrate intake (implying a larger proportion of fat and protein). Taken together, the baseline physical activity and diet results imply that more favorable levels of cardiovascular fitness and body composition were found in youths who participated in greater amounts of free-living vigorous exercise and had a diet pattern that included less protein and more carbohydrate.

The analyses of change scores found intercorrelations between the 3 main outcome variables, suggesting that those who improved the most in cardiovascular fitness also improved the most in %BF and VAT. All 3 physical training process variables were significantly associated with more favorable changes in cardiovascular fitness. When all 3 physical training process variables were considered together as the "physical training dose," the association between them and change in %BF was significant. However, none of the physical training process variables was significantly correlated with individual changes in VAT. These results are consistent with the hypothesis that higher intensity of effort has a favorable effect on cardiovascular fitness but that the association with adiposity is less clear.

It is important to note that the intention-to-treat analyses showed no significant effects of group assignment on %BF or VAT. It is possible that those who perceived that they were gaining less benefit from the physical training were those who tended to attend the sessions <2 d/wk and were therefore omitted from the efficacy analyses. Thus, the effectiveness of prescribing high-intensity exercise for improvement of body composition in the population of obese adolescents is still open to question.

In summary, obese adolescents who participated in an afternoon LSE + physical training program with ≥40% attendance improved in cardiovascular fitness and declined in total body and visceral adiposity to a greater degree than did a group who engaged in the LSE alone. The high-intensity physical training, but not the moderate-intensity physical training, elicited a significantly greater improvement in cardiovascular fitness than the LSE alone, whereas we found no evidence that the moderate- and high-intensity physical training differed in their effects on body composition. The correlational analyses suggested that youths who engaged in more free-living vigorous physical activity had lower baseline %BF and that those who experienced greater doses of physical training during the intervention declined more in %BF. Taken together, these results suggest that for enhancement of cardiovascular fitness it is reasonable to advise obese youths to exercise as vigorously as they can sustain. However, improvements in body composition can apparently be obtained by both moderate and vigorous exercise, with no clear effect of intensity.

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