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Fitness and the effect of exercise training on the dietary intake of healthy adolescents

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OBJECTIVE: In healthy, nonobese, adolescent males and females to: (1) Determine the relationship between fitness and energy intake; (2) assess the effect of five-weeks endurance training on energy intake and food choice and (3) compare food record assessments of energy intake with doubly-labeled water (DLW) measurement of total energy expenditure (TEE).

DESIGN: (1) Cross sectional analysis of fitness and food intake and (2) Prospective, randomized, controlled interventional study of endurance-type exercise training in 44 females and 44 males (age range, 15–17 y).

MEASUREMENTS: Pre and end interventional three day food records were successfully collected from 32 females (15 controls, 17 trained) and 39 males (19 controls, 20 trained). Fitness was assessed from cycle ergometry as peak oxygen uptake normalized both to thigh muscle mass and body weight. Thigh muscle mass was measured by magnetic resonance imaging. TEE using the DLW technique was measured in 12 females (6 controls, 6 trained) and 20 males (10 controls, 10 trained) during weeks 4–5 of the exercise training program (simultaneously with the second assessment of food records). Food record data were analyzed using the Minnesota Nutrition Data System.

RESULTS: Fitness was correlated with self reported total caloric intake in males but not females. In females, there was a significant increase in fat intake ($19.8 \pm 9\%$, $P < 0.05$) and a significant decrease in carbohydrate intake ($-9.8 \pm 4\%$) in the trained subjects. No changes were observed in the control subjects. Energy expenditure (2072 ± 52 kcal/d) was significantly greater than the estimated energy intake (1520 ± 112 kcal/d, $P < 0.007$) during the intervention in the trained, but not control, subjects. However, there was no weight change in either control or trained subjects. In males, no changes were observed in food choice in either control or trained subjects. Similar to the females, energy expenditure (2425 ± 22 kcal/d) was significantly greater than the estimated energy intake (2168 ± 117 kcal/d, $P < 0.05$) during the intervention in the trained, but not control, subjects. No weight changes were observed in either group.

CONCLUSIONS: Fitness is associated with increased self-reported energy intake in males but not females, while exercise training led to alterations in food selection (greater fat and reduced carbohydrate) only in females. These observations could reflect specific gender differences, or, alternatively, the generally lower levels of fitness in the females. The apparent negative energy balance without evidence for weight loss in both the trained males and females suggests a systematic under reporting of food intake during exercise programs in adolescents, and indicates the possibility that errors in self reported food intake might be greater during transitions from one level of energy expenditure to another.

Keywords: exercise; training; dietary intake; energy expenditure; adolescent; females

Introduction

In recent years attention has been focused on the interaction between diet and exercise in children and adolescents because of increased incidence of a sedentary lifestyle, decreased physical fitness and increased obesity.^{1,2} Conversely, adolescents who engage in highly competitive or demanding sports such as gymnastics, dancing or wrestling,³ often combine low energy intake with high energy expenditure. These problems of both over and under nutrition probably lead to impaired health later in life, yet little is known

about the relationship between levels of exercise and natural dietary habits in children and adolescents.

There were two objectives of this study: (1) to examine the correlation between food intake and fitness in a cross-sectional analysis of healthy adolescent males and females and (2) to determine the effects of a controlled, prospective exercise training intervention on spontaneous dietary choices in these same subjects. Our initial hypotheses were: (1) that food intake would correlate with fitness in both males and females and (2) that endurance type training would lead to increases in food intake to balance the increase in energy expenditure that accompanies the exercise training.

In this study, we used food record data from a highly motivated group of adolescent males and females who were part of a fully credited high school summer school course. The studies were performed separately in the males and females over two

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summers at the same location, with the same faculty and investigators. Measurements were made before and at the end of a five-week training intervention in both control and exercise-trained females and males. Finally, the doubly-labeled water (DLW) technique was used to assess total energy expenditure (TEE) in subsets of each group, and these results were compared with the food record data. The effects of this training program on fitness, growth factors and bone formation markers have been published.⁴⁻⁶

Methods

Sample population

Forty-four healthy adolescent girls and 44 healthy adolescent boys volunteered for the study. The participants were all students at Torrance High School (Torrance, CA) and enrolled in an anatomy class during the summer of 1995 (females, July–August) and the summer of 1996 (males) with class hours from 08.00–12.30 h. The study was designed to examine late pubertal subjects with an age range of 15–17 y. The ethnic configuration of the female group was 68% Asian, 21% Caucasian and 11% Hispanic. The ethnic configuration of the male group was 71% Asian, 20% Caucasian and 9% Hispanic. No attempt was made to recruit subjects who participated in competitive extramural athletic programs.

Assessment of pubertal status was performed by history and physical examination in all of the subjects. In the females, 95% were found to be at Tanner stage V, using breast development and pubic hair criteria. In the males, 70% were at Tanner level V, 25% at Tanner level IV and 5% at Tanner level III, using penile length, testicular volume and pubic hair criteria. A standardized test developed by Killen *et al*⁷ was used to screen the subjects for eating disorders, and no disorders were detected.

Subjects were randomized to control ($n = 22$) and training ($n = 22$) groups. All subjects participated in the daily two-hour teaching program. During the remaining time, the training group members underwent endurance-type training, consisting of running, aerobic dance, competitive sports (for example, basketball) and occasional weight-lifting. These activities were varied in duration and intensity throughout the week primarily to encourage maximal participation of the subjects. On average, 'aerobic' or endurance type activities accounted for about 90% of the time spent in training. Training was directed by a member of the Torrance High School faculty. Control group subjects participated in a computer workshop designed to improve their computer skills and used this time to analyze some of the data collected from the study. No attempt was made to influence extracurricular levels of physical activity in either the control or training groups.

All 44 females who participated in the study completed the full five-week protocol as members of

either the control or trained group. Of the 44 males who began study, five subjects (three from the control group and two from the training group) withdrew due to academic and/or disciplinary reasons. The two subjects who withdrew from the training group, did so two days prior to the final examination, and reported that the difficulty of the training protocol was not the reason for their decision. Thus, 39 male subjects (19 from the control group and 20 from the trained group) completed the summer program.

Staff members involved in collecting dietary questionnaires, fitness assessment, MRI evaluation of thigh musculature and TEE assessment, were blinded to the subject's group. No attempt was made to influence food intake patterns of either the control or training subjects. The study was approved by the Institutional Human Subject Review Board and informed consent was obtained from the subjects and their parents or guardians.

Assessment of training input and extramural physical activity

In the females, 10 control group subjects and 10 training group subjects wore portable heart rate monitors from 07.00–12 noon on a single day to gauge the impact of the training. The data from the subjects were superimposed and averaged, and are shown in Figure 1. A self-assessment questionnaire was developed to estimate the time spent in extramural programs of physical activity in the control and trained group during the period of the intervention. All female subjects participated in this assessment. The questionnaire was not used for the male subjects.

Dietary assessment

All subjects were instructed on how to keep a three-day food record and were evaluated for understanding and accuracy by administration of a 24 h recall, prior

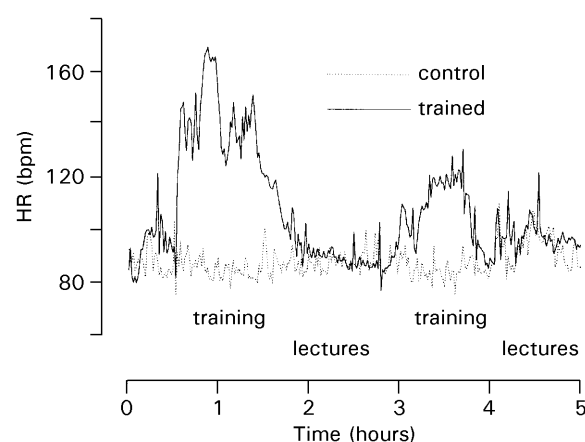


Figure 1 Mean heart rates in the female adolescents during the morning sessions obtained from continuous, portable HR monitoring. The effect of the training sessions is readily apparent. Mean HR in the control group ($n = 10$, 88 ± 0.3 bpm, dotted line) was significantly less than in the training group ($n = 10$, 106 bpm, $P < 0.0001$, solid line).

to initiation of the study. Subjects kept two three-day food records, one at baseline and one at the end of the five-week program. The food record data were reviewed by project nutritionists and checked for omissions (for example, to verify if dressing was used on a salad listed as ingested with no dressing) and errors (for example, inappropriate portion size). This approach has been validated recently in adolescents by Crawford *et al.*⁸

In the female study, five students from the training group failed to complete the post study food record. In the control group, three students did not complete the post study food record and four other students had energy intakes more than three standard deviations above or below the mean. These four records were deemed unreliable, based on unrealistic portion sizes that were reported by the students. Thus, pre- and post-intervention three-day food record data in the females were available on 32 students (15 from the control group and 17 from the training group). In the male study, pre- and post-intervention three-day food record data were available in all subjects (19 controls and 20 trained subjects).

The food records were analysed using the Minnesota Nutrition Data System (University of Minnesota, 1994). This set of computer algorithms calculates total energy intake and the proportion of the total energy intake derived from protein, fat and carbohydrate.

Measurement of TEE

The DLW technique was used as previously described^{4,9} to measure TEE for a 10-day period beginning in week 4 of the protocol. Ideally, pre- and post-intervention measurements of TEE using DLW would have been performed; however this was prohibited by the extremely high cost of H₂¹⁸O. A subset of subjects from the control and training groups (females, *n* = 12 (6 controls) and males, *n* = 20 (10 controls)) were randomly selected for TEE measurements. Note that the second food record was performed during the fifth week of training and this corresponded to the last three days of sample collection for the DLW assessment of TEE; thus, the measurements probably reflected similar conditions of energy expenditure and intake. These data were used for the comparison between energy intake and expenditure.

After a baseline urine sample was obtained, each subject was given a standard oral dose of DLW. In order to minimize calculation error, a standard dose of 25 ml of a 1:1 mixture of ²H₂O and H₂¹⁸O (99% enriched from Isotec Inc., Williamsburg, OH) was given. The dose is calculated to provide an average of 0.22 g/kg of ²H₂O or H₂¹⁸O with a range of 0.15–0.29 g/kg. A urine sample was obtained 2 h later and daily for the next 10 d. Oxygen and hydrogen isotopic ratios were measured by standard techniques with a Finnegan Delta-S gas isotope-ratio mass spectrometer. The isotope ratio data were analyzed using linear

regression analysis after log transformation using standard techniques.¹⁰

MRI of thigh musculature

We chose to examine the musculature of the right thigh, since these muscles would be largely involved in the endurance type training program described above. MRI has been used previously to assess muscle mass.^{4,11,12} MRI was performed on a General Electric 1.5 Tesla whole body MRI System. A body coil was used for both signal detection and for RF transmission or imaging. The subject was positioned with the lower extremities at the isocenter of the magnet bore. Pilot image coronal slices of the right thigh were obtained to select an image which included the distal femur. Twelve axial slices from above the knee to below the femoral neck were obtained. These axial slices were 20 mm thick, with no gap, and obtained with a T1 weighted sequence with a time-to-echo of 12 msec and repetition time of 400 msec. The matrix was 192 × 256 with two acquisitions at each phase encode step.

The thigh muscle cross sectional areas of consecutive 2 cm slices were easily recognizable and measured using computerized planimetry. The volume (cm³) of each slice was estimated as CSA (cm²) · 2 cm. These were then totaled to calculate the muscle volume.

Fitness assessment

As a global estimate of 'fitness', we used the peak $\dot{V}O_2$ measured before, and immediately after, the five-week protocol in all subjects. Each subject performed a ramp-type progressive exercise test on a cycle ergometer in which the subject exercised to the limit of their tolerance. Gas exchange was measured breath-by-breath,¹³ and the peak $\dot{V}O_2$ was determined as previously described in children and adolescents.^{14,15}

Scaling fitness to body size

To minimize the confounding effects of body size *per se* on the assessment of fitness, we normalized the peak $\dot{V}O_2$ to body weight (ml/min/kg). The normalization to body weight is a standard approach, although, it is recognized that this strategy does not completely eliminate confounding factors due to size.^{16,17} Allometric equations are frequently used to determine the relationship between body size and function^{18–20} and have the form:

$$\text{peak } \dot{V}O_2 \propto M^b$$

where *M* is a measure of body mass and *b* is the scaling factor.

One of the problems with using a per weight normalization, is that peak $\dot{V}O_2$ does not necessarily scale to body mass to the power of 1.0. As a consequence, normalizing the peak $\dot{V}O_2$ to body weight might lead to erroneous interpretations of the

data. Therefore, we also calculated the scaling factor for the relationship between peak $\dot{V}O_2$ and thigh muscle mass since the latter is known to be the major determinant of peak $\dot{V}O_2$.²¹ We then normalized the peak $\dot{V}O_2$ to thigh muscle mass.

Statistical analysis

Body weight, energy intake, TEE and fitness, prior to the training intervention, were compared between males and females using unpaired *t* test. Total energy intake and %protein, %fat and %carbohydrate, prior to the training intervention, were compared between the control and training groups using the unpaired *t* test. In the subgroup of subjects in whom both energy intake by food record and TEE by DLW were measured, results of the two techniques were compared using paired *t* tests.

Cross-sectional correlations. Standard techniques of linear regression were used to compute the correlation coefficient between fitness and food intake (as well as each of the components of food intake—protein, fat and carbohydrate), and between fitness and TEE.

Scaling factors were determined using linear regression and the log-log transform of the scaling equation shown above.

Prospective interventional analysis. Changes in dietary intake associated with the training intervention were evaluated separately among males and females using multivariate analysis of variance (MANOVA) with repeated-measures. Statistical significance was taken at the $P < 0.05$ level. Data are presented as mean \pm standard error (s.e.m.).

Results

Cross-sectional analyses

The scaling factor for peak $\dot{V}O_2$ and body weight was 0.75 ± 0.12 in the males, and 0.69 ± 0.17 in the females. In contrast, the scaling factor for peak $\dot{V}O_2$ and thigh muscle mass was 0.94 ± 0.15 in the males and 0.93 ± 0.14 in the females. These latter two values were not significantly different from 1.0.

The correlations between peak $\dot{V}O_2$ normalized to body weight and peak $\dot{V}O_2$ normalized to thigh muscle mass and: (1) Total energy intake (Figure 2);

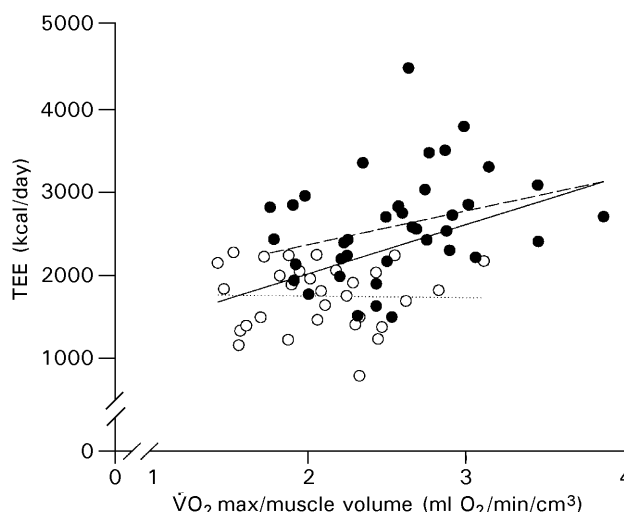


Figure 2 Correlation between fitness (as peak $\dot{V}O_2$ normalized to thigh muscle volume) and self reported total energy intake in adolescent males and females. The solid line indicates the statistically significant regressions for the combined group ($n=71$); the dotted line indicates the regression for females only ($n=32$, NS); and the dashed line indicates the statistically significant regression for the males ($n=39$). Qualitatively similar correlations were found between peak $\dot{V}O_2$ normalized to body weight and total energy intake.

(2) % protein intake; (3) % fat intake and (4) carbohydrate intake are shown in Table 1. In the group as a whole, fitness correlated with total energy intake and each of its elements. However, when analyzed according to gender, we found significant correlations only in the males. As can be seen in Table 1, results were qualitatively similar when peak $\dot{V}O_2$ was normalized either to body weight or to thigh muscle volume.

In all subjects who performed the DLW test for energy expenditure, TEE normalized to body weight was weakly but significantly correlated with peak $\dot{V}O_2$ normalized to body weight ($r = 0.37$, $P < 0.05$). However, there was no correlation between TEE and peak $\dot{V}O_2$ when these variables were normalized to thigh muscle volume.

Anthropometric evaluation

Females. We previously reported⁴ that there were no significant differences in height and weight between the training and the control groups before the intervention. There were no significant changes in height and weight over the five-week observation period in either group.

Table 1 Relationship between fitness as peak $\dot{V}O_2$ normalized to both body weight (wt) and thigh muscle volume (m vol), and caloric intake in healthy adolescent males and females

Intake	All subjects ($n=71$)		Males ($n=39$)		Females ($n=32$)	
	Peak $\dot{V}O_2$ /wt.	Peak $\dot{V}O_2$ /m vol.	Peak $\dot{V}O_2$ /wt.	Peak $\dot{V}O_2$ /m vol.	Peak $\dot{V}O_2$ /wt.	Peak $\dot{V}O_2$ /m vol.
Total energy (kcal/d)	$r=0.56$, $P < 0.00001$	$r=0.45$, $P < 0.00001$	$r=0.32$, $P < 0.03$	$r=0.33$, $P < 0.03$	$r=0.19$, NS	$r=0.2$, NS
Protein (%)	$r=0.56$, $P < 0.00001$	$r=0.41$, $P < 0.0002$	$r=0.21$, NS	$r=0.09$, NS	$r=0.28$, NS	$r=0.26$, NS
Fat (%)	$r=0.48$, $P < 0.00001$	$r=0.36$, $P < 0.001$	$r=0.31$, $P < 0.03$	$r=0.27$, $P < 0.05$	$r=0.13$, NS	$r=0.03$, NS
Carbohydrate (%)	$r=0.46$, $P < 0.00001$	$r=0.41$, $P < 0.0002$	$r=0.23$, NS	$r=0.23$, NS	$r=0.02$, NS	$r=0.06$, NS

Males. We previously reported⁶ that there were no significant differences in height and weight between the training and the control groups before the intervention. There were no significant changes in height and weight over the five-week observation period in either group.

Impact of the intervention on heart rate (HR) and extramural activity (female subjects only)

The group mean averages for HR monitoring for the morning sessions are shown in Figure 1. The effect of the training sessions is readily apparent, and mean HR in the control group (88 ± 0.3 bpm) was significantly less than in the training group (106 ± 1 bpm, $P < 0.0001$). Control group subjects participated in 3.3 ± 0.7 h/week of extramural exercise activity while in the training group the mean value was 2.2 ± 0.7 h/week ($P = \text{NS}$).

Food record data

Females. Total energy intake, percent energy derived from protein (%protein), from fat (%fat) and from carbohydrate (%carbohydrate) of the females before and after the training intervention are summarized in Table 2. There were differences observed between the subjects randomized to the control and trained groups, even before the intervention began. Control group subjects had significantly higher %fat and lower %carbohydrate (Table 2). There were no significant changes in total energy intake, %protein, %fat and %carbohydrate in the control group subjects over the course of the study period.

In the trained subjects, there was no change in total energy intake over the course of the study period. However, changes in %fat were significantly greater than control ($P < 0.05$), and changes in %carbohydrate were significantly less than control ($P < 0.05$) (Figure 3).

Males. Total energy intake, % protein, % fat and % carbohydrate are summarized in Table 3. There were no differences in these variables between the control and trained subjects at the beginning of the study. In both control and trained subjects there were no significant changes in total energy intake, %protein, %fat

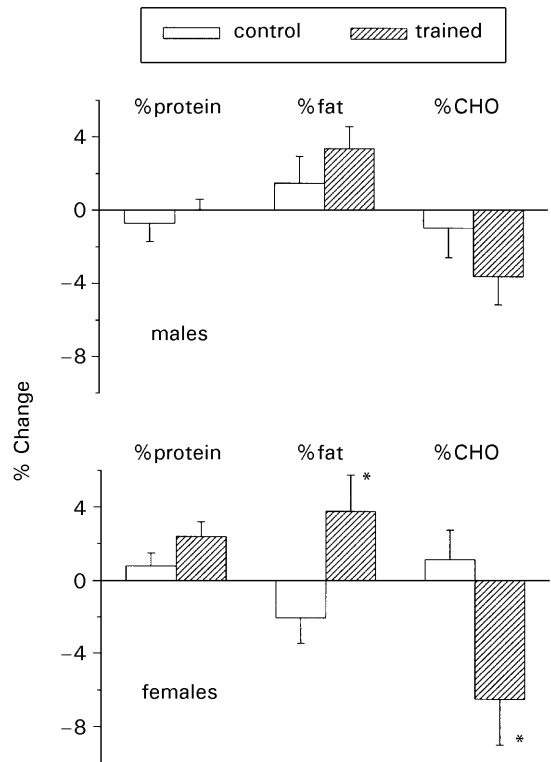


Figure 3 The effect of training on food selection in adolescent males and females. No significant effects were observed in the males. In the females, training led to significant increases in %fat and decreases in %carbohydrate (* $P < 0.05$ by MANOVA).

and %carbohydrate over the course of the study period (Figure 3).

Endurance training and TEE

TEE and other variables of the DLW assessment in control and training, male and female subjects, are shown in Table 4. TEE normalized to thigh muscle volume was significantly greater in the trained subjects in both male and female groups.

TEE vs total energy intake (Figure 4)

Females (subgroup: six control, six trained). In the control group subjects, there was no significant difference between TEE (by DLW) and total caloric intake (by food record) during the study period (1791 ± 42 kcal/d by DLW vs 1811 ± 213 kcal/d by food record). In contrast, TEE was significantly higher

Table 2 The effect of five weeks endurance-type training intervention on dietary intake in adolescent females

	Control group (n = 15)		Training group (n = 17)	
	Pre	Post	Pre	Post
Energy intake (kcal/d)	1816 ± 94	1680 ± 100	1705 ± 73	1805 ± 90
Protein (%)	15.0 ± 0.8	15.8 ± 0.7	13.8 ± 0.5	16.2 ± 0.9
Fat (%)	33.3 ± 1.0	31.1 ± 1.8	27.6 ± 1.4**	31.5 ± 1.5*
Carbohydrate (%)	53.1 ± 1.7	54.3 ± 2.1	59.8 ± 1.4**	53.3 ± 2.1*

* Compared to preinterventional values ($P < 0.05$).

** Compared to control group values ($P < 0.05$).

Data are presented as mean ± standard error (s.e.m.).

Table 3 The effect of five weeks endurance-type training intervention on dietary intake in adolescent males

	Control group (n = 19)		Training group (n = 20)	
	Pre	Post	Pre	Post
Energy intake (kcal/d)	2583 ± 149	2380 ± 160	2709 ± 127	2453 ± 143
Protein (%)	17.2 ± 0.8	16.5 ± 0.9	15.1 ± 0.7	15.2 ± 0.7
Fat (%)	31.2 ± 1.0	32.7 ± 0.9	29.5 ± 1.5	32.9 ± 1.5
Carbohydrate (%)	52.0 ± 1.0	51.0 ± 1.2	56.1 ± 1.9	52.5 ± 1.9

Data are presented as mean ± standard error (s.e.m.).

Table 4 Variables derived from doubly-labeled water (DLW) measurement of total energy expenditure (TEE)

	Female		Male	
	Control (n = 6)	Trained (n = 6)	Control (n = 6)	Trained (n = 6)
TEE/Thigh muscle volume	1.66 ± 0.18	2.25 ± 0.16*	1.59 ± 0.11	1.86 ± 0.1*
Dilution space ¹⁸ O-N(¹⁸ O) (moles)	1590 ± 120	1548 ± 41	1810 ± 10	1716 ± 16*
Dilution space D ₂ -N(D ₂) (moles)	1651 ± 114	1609 ± 41	1992 ± 26	1863 ± 25*
N(D ₂)/N(¹⁸ O)	1.04 ± 0.01	1.04 ± 0.01	1.10 ± 0.01	1.09 ± 0.01
Rate coefficient ¹⁸ O-K(¹⁸ O)	0.10 ± 0.01	0.12 ± 0.01	0.10 ± 0.01	0.12 ± 0.01*
Rate coefficient D ₂ -K(D ₂)	0.07 ± 0.01	0.09 ± 0.01	0.07 ± 0.01	0.09 ± 0.01*
CO ₂ production (mole/d)	14.8 ± 0.5	16.8 ± 0.4*	17.1 ± 0.4	19.7 ± 0.2*

Data are presented as mean ± s.e.m.

* *P* < 0.05 for control vs trained subjects.

than total caloric intake in the trained subjects during the training period (2072 ± 52 kcal/d by DLW vs 1520 ± 112 kcal/d by food record, *P* < 0.007) (Figure 4).

Males (subgroup: 10 control, 10 trained). Results in the males paralleled those observed in the females. In the control group subjects, there was no significant difference between TEE and total energy intake during the study period (2100 ± 47 kcal/d by DLW vs 2073 ± 184 kcal/d by food record). In contrast, in the training group subjects, TEE was significantly greater than total caloric intake during the training intervention (2425 ± 22 kcal/d by DLW vs 2168 ± 117 kcal/d by food record, *P* < 0.05) (Figure 4).

Comparison of females and males

At the beginning of the study, the males were heavier than the females to a small but significant degree (64 ± 2 kg in males vs 58 ± 2 kg in females, *P* < 0.05). Energy intake was significantly greater in the males (2648 ± 97 kcal/d) compared with the females (1757 ± 69, *P* < 0.0001). Fitness was also greater in the males compared with the females, whether peak $\dot{V}O_2$ was normalized to body weight (39.4 ± 0.8 ml/min/kg in males compared with 30.9 ± 0.8 ml/min/kg in females, *P* < 0.005) or to thigh muscle volume (1.78 ± 0.04 ml/min/cm³ in males compared with 1.55 ± 0.04 ml/min/cm³ in females, *P* < 0.00001).

We compared the TEE normalized to body weight between males and females. Using both control and trained subjects, the daily energy expenditure normal-

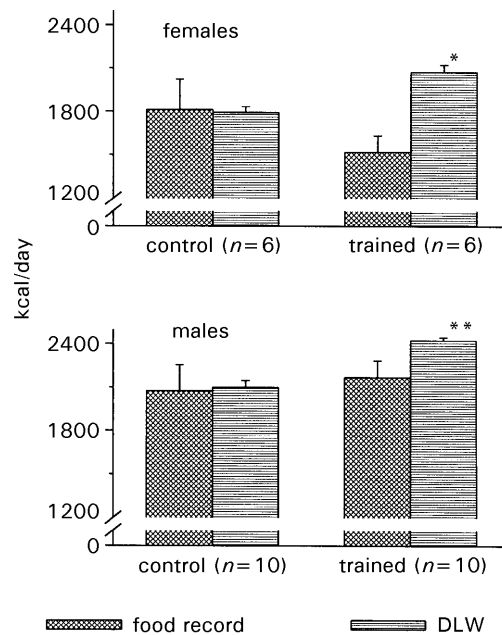


Figure 4 Comparison between self-reported total energy intake and total energy expenditure by doubly-labelled water (DLW) in adolescent males and females. The data were comparable in the control subjects. In trained subjects, however, energy expenditure by DLW exceeded energy intake by food record in females (**P* < 0.007 by paired *t* test) and males (***P* < 0.05 by paired *t* test).

ized to body weight in males (38.1 ± 1.7 kcal/d/kg) was significantly greater than in females (33.1 ± 1.7 kcal/d/kg, *P* < 0.05). However, these differences disappeared when TEE was normalized to thigh muscle volume, a better index of lean body mass than is body weight (1.73 ± 0.08 kcal/d/cm³ in males compared with 1.95 ± 0.25 kcal/d/cm³ in females, *P* = NS).

Discussion

This is one of the first studies, to our knowledge, focused on nonobese, healthy and normally active American adolescents, in which food intake was compared with energy expenditure, and the influence of fitness and exercise training on these variables was determined. We found a moderate but highly significant correlation between self recorded total energy intake and fitness in the combined group of healthy, nonobese male and female adolescents (Figure 2). This correlation was not observed in the females. Thus, our hypothesis that food intake would be correlated with fitness was only partially supported. However, the positive correlation between fitness and fat intake in the boys is consistent with previous observations in humans suggesting that increased levels of activity are associated with increased fat consumption.^{22–24}

The mechanisms for the gender effect are not readily apparent and might involve differences in the way adolescent males and females perceive and report food intake (for example, dietary restraint). However, it is noteworthy that the females were less fit than the males. This suggests the possibility of a more generalised biological mechanism. In this alternative paradigm, there exists some 'fitness-threshold' for food intake. Below a particular level of energy expenditure, food intake is relatively independent of fitness. Above this putative threshold, as seen in the males in the present study, energy intake is correlated with food intake.

Along these lines, there exists substantial controversy regarding the most appropriate way to normalize indices of fitness (for example, the peak $\dot{V}O_2$) to body size.^{16,17} This is particularly important in the present study in which comparisons between males and females are made and in which body weight between the two groups differed. By normalizing to thigh muscle mass, we minimized a number of confounding effects of normalizing to body weight alone. First, we found that the scaling factor of peak $\dot{V}O_2$ and muscle mass was not different from 1.0; thus additional 'artefact' is not introduced when dividing peak $\dot{V}O_2$ by muscle volume. Secondly, we normalized estimates of energy expenditure to muscle size, the tissue that determines the increase in energy expenditure that accompanies physical activity. As a result, significant differences that were noted between males and females when TEE was normalized to body weight, disappeared when TEE was normalized to the exercising tissue as estimated by the thigh muscle volume.

Another potentially confounding methodological effect concerns the magnitude of the training input and the effect of the intervention on the control subjects. In the females, we demonstrated through the use of HR monitors and questionnaires, that the training intervention was indeed physiologically

effective—demonstrated by the markedly elevated HR during the two morning training sessions (Figure 1). Nor did it appear that the control group subjects 'compensated' for the lack of morning exercise by significant increases in extramural activity. Although these measurements were not made in the males, informal assessments suggested to us a similar pattern.

The study demonstrated that a relatively brief program of endurance type training led to self-reported, spontaneous alteration in food choices in the trained females who increased fat and reduced carbohydrate. Similar results were not observed in the males. In studies of adults, there is marked variability in the effects of training on food choices (for example, see Reference 25). Some of the discrepancy may be methodological in origin, due to different intensity and duration of the exercise 'input'. For example, Verger *et al*^{26,27} concluded that human food choices after a single exercise bout, transiently promote protein intake and inhibit carbohydrate intake.

It is possible that our results in the females were confounded by the random, small but significant, preintervention differences in %fat and %carbohydrate (Table 2) between the control and training groups (although no differences in total food intake were noted between the groups). However, the significant changes were observed only in the training group, consistent with the notion that the training was, indeed, the major factor. In addition, the effect of exercise training on food selection in the present study is consistent with observations of previous investigators. Kiens *et al*²⁸ showed that 12 weeks of physical conditioning in middle-aged men, led to increased energy intake that was almost entirely for dietary fat. Reggiani *et al*²³ showed that fat intake was increased and carbohydrate decreased in young women who were habitually physically active for at least two years. These previous result, along with the observations of the present study, suggest that the effect of exercise training on food selection occurs relatively early and specifically involves an increase in fat and a decrease in carbohydrate.

In contrast, we did not find statistically significant training-associated alterations in food choices in the males (however, note that %fat did increase in the trained males, but not significantly so, Figure 3). The mechanism for these gender differences is unknown. The males, as noted, were generally fitter than the females prior to the training intervention, suggesting higher levels of physical activity even before the training intervention began. In addition, our cross sectional analysis at the beginning of the study showed that fitter boys tended to consume greater quantities of fat. Thus, it is possible that any effect of a formal training program on dietary choices was attenuated by the generally higher fitness and possibly higher levels of physical activity in the males.

An important aspect of this study, was the ability to simultaneously assess energy balance using food record measurement of energy intake with DLW

measurement of energy expenditure. The control subjects were weight-stable during the intervention, and consistent with this was the balance between total energy intake and energy expenditure (Figure 4). The three-day food record methodology yielded results comparable to those obtained by the more physiological DLW technique in these adolescent subjects (males and females).

Agreement between food record and DLW measurement of energy intake and expenditure in human subjects has typically not been very good.^{29–31} The subjectivity and variability of food record techniques are often identified as the source of error in these studies, and a number of investigators believe that under recording of self reported food intake often occurs.³² We found an intriguing inconsistency between the DLW measurement of energy expenditure and food record assessment of energy intake that might shed some light on methodological errors inherent in food record data. In the trained males and females, energy expenditure exceeded self-reported energy intake (Figure 4), but despite this apparent negative energy balance, there was no weight loss in any of the groups.

As noted, the discrepancy appeared in the training, but not the control, subjects during two separate summers, in different groups of adolescent males and females. This suggests the possibility that underestimation of food record data is most pronounced in subjects undergoing a transition from one steady-state of energy expenditure to another. We speculate that subjects not yet accustomed to their new patterns of food intake may have difficulty in its accurate reporting. In addition, fitness and muscle tone were improving in the training group subjects over the course of the intervention.^{4,6,9} Perhaps these subjects were more sensitive to the effects of food intake on body composition and body image. As a consequence, the training group subjects may have subconsciously underestimated total energy intake, but not the relative contributions of the kinds of foods they were eating.

Conclusion

In a population of healthy, nonobese adolescents, pre-existing levels of fitness, and the imposition of an exercise training program, modulated energy intake and food selection. Fitness was associated with increased self-reported energy intake in males but not females, while exercise training led to alterations in food selection (greater fat and reduced carbohydrate) only in females. These observations could reflect specific gender differences or, alternatively, the generally lower levels of TEE and fitness of the females.

The apparent negative energy balance without evidence for weight loss in both the trained males and females, suggests a systematic under reporting of food

intake during exercise programs in adolescents, and suggests the possibility that errors in self reported food intake might be greater during transitions from one level of energy expenditure to another. A weakness of the present study was the lack of TEE measurements by DLW before and during the intervention, since this information might have shed light on the reasons for the discrepancy between TEE and total caloric intake. But as noted above, DLW measurements of TEE are of necessity limited, due to the high cost of isotope and analysis. Our data suggest, unfortunately, that in order to gauge the relationship between energy intake and energy expenditure in dynamic interventions, multiple measurements cannot be avoided.

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