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ORIGINAL ARTICLE

Immediate post-exercise energy intake and macronutrient preferences in normal weight and overweight pre-pubertal children

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Abstract

Objective. To examine the immediate effect of three different types of popular exercise activities on food intake and preferences in normal weight and overweight children *Subjects and methods.* Forty-four (22 overweight) age and gender matched, pre-pubertal children participated in four separate visits. All performed three typical, 45 min, aerobic, indoor resistance and swimming exercise sessions and a control visit (no exercise). A similar buffet lunch was served immediately after each visit to both groups. The total energy intake and relative consumption of carbohydrates, fat and protein were recorded. *Results.* In the normal weight children, total energy intake was reduced following exercise. This difference reached statistical significance only following the resistance-type exercise (14.0±1.4 [58.6±5.9] versus 19.4±1.7 [81.2±7.1] kcal/kg [kJ/kg], in resistance exercise and control, respectively; $p<0.008$). The different types of exercise were associated with increased relative consumption of carbohydrate and decreased consumption of fat. In contrast, in the overweight children, total energy intake was increased following exercise. This increase reached statistical significance following the swimming exercise session (23.0±2.4 [96.3±10.0] versus 18.5±1.5 [77.4±6.3] kcal/kg [kJ/kg] in swimming and control, respectively; $p<0.02$). All types of exercise lead to a significant increase in the relative consumption of proteins in the overweight children. Finally, the total energy intake was significantly greater in the overweight children following the control (i.e., no exercise), and all types of exercise sessions. After normalization of the total energy intake to body mass, this difference remained significant only following the swimming practice (23.0±2.4 [96.3±10.0] versus 15.9±1.6 [66.6±6.7] kcal/kg [kJ/kg] in overweight and normal weight, respectively; $p<0.04$). *Conclusions.* Understanding the complicated relationship between exercise, appetite, and food choices may help us to optimize exercise interventions for this unique population, and to select the best exercise protocols to achieve a desired energy balance. Food intake and preferences in response to acute exercise are different in normal weight and obese children.

Key words: *Exercise, macronutrient choices, prepubertal, resistance, swimming*

Introduction

Activity, or inactivity, and diet are crucial elements of life-style. Their interrelations have powerful effects on health and well-being in both adults and children. Although the mechanisms responsible for the increasing prevalence of childhood obesity are not completely understood, there is no doubt that life-style changes associated with increased energy intake and decreased energy expenditure probably play a major role (1,2).

Childhood obesity is associated with a higher prevalence of co-morbidities, such as hyperlipidemia, hypertension, insulin resistance, non-insulin dependent diabetes mellitus, the metabolic syndrome and arteriosclerosis later in life (3,4). Treatment programs for childhood obesity require a multi-disciplinary approach, and should include dietary changes, nutritional education, changes in physical activity patterns and behavioral modification (5,6).

It is surprising therefore, that relatively few studies examined the relationships between physical activity and nutrition in obese children. Animal and human adult studies suggested that appetite is suppressed and energy intake is reduced immediately after strenuous exercise (7,8). In addition, exercise-induces changes in counter-regulatory hormones (e.g., epinephrine, growth hormone) and free fatty acids resulting in increased carbohydrate

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and decreased fat intake immediately following exercise (9).

To the best of our knowledge, the effect of different types of physical activity (e.g., aerobic, anaerobic, or resistance) on appetite and food choices was not previously studied in obese children. Understanding the effect of exercise on appetite and food choices may help us optimize exercise-training interventions and select the best exercise protocols for this population. Therefore, the aim of this study was to examine the immediate effect of different types of popular exercise (aerobic, resistance and swimming) on energy intake and macronutrient preferences in pre- and early-pubertal, normal weight and obese children. We hypothesized that following exercise the total energy intake will be reduced, and that exercise will lead to a relative increase in carbohydrate consumption. We further speculated that these changes will be more significant following aerobic exercise and swimming. Finally, as obese children are more sensitized to food-related stimuli (10), we hypothesized that overweight or obese children would be more likely to overcompensate for the energy expended in exercise than the normal weight children relative to body weight.

Subjects and methods

Twenty-two healthy, normal weight (aged 6.2–10.9 years; 5 males; 17 females) and 22 overweight and obese (aged 6.5–11 years; 7 males; 15 females) pre- and early-pubertal children participated in the study. The study was approved by the Institutional Review Board of the Meir Medical Center, and all the participants and their parents signed an informed consent form. The study was performed at the Child Health and Sports center at the Meir Medical Center, Tel-Aviv University, Israel. The participants came to the center four times at noon (during two weeks of school break). Obese and normal weight children participated in separate sessions. All participants were questioned by the study team about their physical activity level before inclusion. None of the participants (normal and overweight) were engaged in regular exercise for more than two hours per week (including mandatory physical education classes in school for 45 minutes, twice a week). All children were familiar with swimming, and training sessions were performed when the pool was closed to the general public to optimize the comfort and minimize embarrassment of the children (especially the obese children). None of the children were acquainted with resistant training using hydraulic weight lifting system, but all were familiar with the resistant training games (i.e., jumping games etc.), exercising against the resistance of their body weight.

Anthropometric measurements

Standard, calibrated scales and stadiometers were used to determine height, weight, and body mass index (BMI) (kg/m^2) at the first visit to the center. As BMI changes with age, BMI-for-age percentiles were calculated according to the Center for Disease Control growth charts (11). Tanner staging by breast development for females and pubic hair for males was assessed by a pediatric endocrinologist (12).

Study procedure

Children were asked to refrain from exercise each morning before the study. During the control visit (no exercise) the children watched a video movie for 45 minutes and then ate the buffet lunch. In the other three visits the participants performed three different types of typical training sessions (outdoor aerobic, indoor resistance and a swimming session). The training sessions were performed in groups of 10–12 children at a time, in random order, and lasted 45 minutes. Lunch was served within 30–45 minutes after the end of the training session.

The outdoor aerobic training session was designed to mimic the type and intensity of exercise that elementary school children normally perform. The activities were designed primarily as games to encourage the enthusiasm and participation of the subjects, and were divided into approximately 50% team and 50% running games. The indoor resistance training consisted of circuit training using a hydraulic weight lifting system designed for children. In addition, some of the resistance activities were also designed as games in order to optimize participation (i.e., jumping games etc.), and the children exercised against the resistance of their body weight. The swimming training session was designed to include mainly aerobic type exercise. The activities included swimming games and other aerobic-type water team sports games (i.e., water polo). Heart rate was monitored during the training sessions using a Polar heart rate monitor (Polar Accurex Plus, Polar Electro, Woodbury, NY), and manually every 15 min, and the average exercise session heart rate was calculated. All training regimes included brief warm-up and cool-down exercises. Children were permitted free access to water and encouraged to drink when thirsty and rest briefly when fatigued. No muscular discomfort was reported by the participants. The ambient temperature during the outdoor aerobic session was 27–28°C, humidity of 45–50%, and the water temperature during the swimming session was 28–28.5°C (Indoor pool).

Buffet lunch and nutritional assessment

Children were given dietary guidelines for dinner consumed the day before, and breakfast on the day of each visit, so that their diet was controlled for 24 h prior to the exercise. The participants were instructed to eat a similar regular meal before each visit, and not to eat or drink (other than water) after breakfast until the buffet lunch was served. A similar buffet lunch was served to the normal weight and to the overweight children after each different session (the same buffet for both groups after aerobic exercise etc.). The buffet lunch included three different types of meat (e.g., beef, chicken etc.), three different types of side dishes (e.g., potato, rice, cooked vegetables etc.), two types of salads (e.g., vegetable, coleslaw etc.), two types of deserts, and three types of drinks (e.g., water, juice and soda). While the content of the food was similar in each buffet lunch, food was prepared to look different at each meal. This was done because previous studies indicated that if exactly the same buffet lunch is served several times, children make their choices in the first meal and eat exactly the same in the following meals (13).

Each participant received a numbered tray, and was told to keep that tray throughout lunch. All the foods were served to dishes that were kept on the individual tray, and the participants were instructed to leave all leftovers on the tray at the end of lunch. Meals were pre-portioned and food items were weighed to the nearest gram by the nutritionist before eating, and the leftovers were weighed at the end of lunch. Any additional foods were also weighed and marked separately (e.g., second serving of a specific food or the number of drinks). Photo pictures of the trays were taken after serving and before eating, and again at the end of lunch.

Food intake was analyzed using the Israeli Ministry of Health tables. A computerized algorithm was used to calculate the total energy intake and the proportion of the total calorie intake derived from protein, fat, and carbohydrate.

Table I. Anthropometric characteristics of the study participants.

	Normal weight (n=22)	Overweight (n=22)
Age (years)	9.4±0.3	9.1±0.6
Gender (Female/male)	17/5	15/7
Height (cm)	136.1±1.3	139.4±2.5
Weight (kg)	31.7±1.1	46.9±2.2*
BMI (kg/m^2)	17.0±0.4	23.9±0.6*
BMI percentile (%)	53.2±5.0	95.2±0.8*
Pubertal stage (Tanner 1/2)	(15/7)	(15/7)

*$p<0.0001$. BMI: Body mass index.

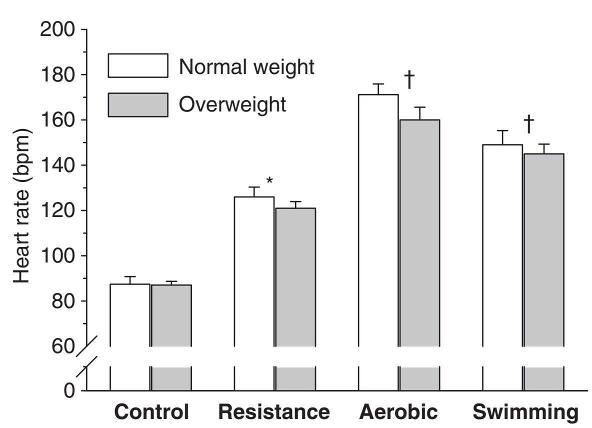
Statistical analysis

Two sample t-test was used to determine baseline differences between the normal weight and overweight children. A two-way repeated measure ANOVA (with Bonferroni post-hoc test) was used to compare the effect of different type of training on heart rate, energy intake (total and normalized to body weight [energy/kg]) and the relative consumption of protein, fat, and carbohydrate in the normal weight and overweight children. Exercise type served as the within group, and weight as the between group factor. Statistical significance was taken at $p<0.05$. Chi-square test was used to determine the differences in the number of participants for each group that increased their caloric intake per kg body weight by more than 5%. Data are presented as mean ± standard deviation (SD).

Results

Anthropometric characteristics of the study participants are shown in Table I. As defined, body weight, BMI and BMI percentile were significantly greater in the overweight children. There was no age, gender or pubertal status difference between the groups.

Mean heart rate of the study participants during the three exercise sessions and the control visit (no exercise) is shown in Figure 1. In both groups, heart rate was significantly higher during the outdoor aerobic and swimming session compared with the resistance session and control session. In both groups heart rate during the resistance session was higher compared with the control session. There were no significant differences in mean heart rate between the normal weight and the overweight children during



*$p<0.05$, significant difference from control.
†$p<0.05$, significant difference from resistance exercise and control.

Figure 1. Mean heart rate during the three different types of exercise sessions and during the control (no exercise) visit.

Table II. Relative intensity (as percent of training time) of exercise by heart rate zones. There were no significant differences between overweight and normal weight children in the percent time spent at each heart rate zone in none of the exercise sessions.

	Normal weight			Overweight		
Heart Rate Zone (beats per minute)	>170	140–170	90–140	>170	140–170	90–140
Aerobic	43 %	32%	25%	41%	32%	27%
Swimming	32%	40%	28%	30%	38%	32%
Resistance	12%	18%	70%	10%	17%	73%

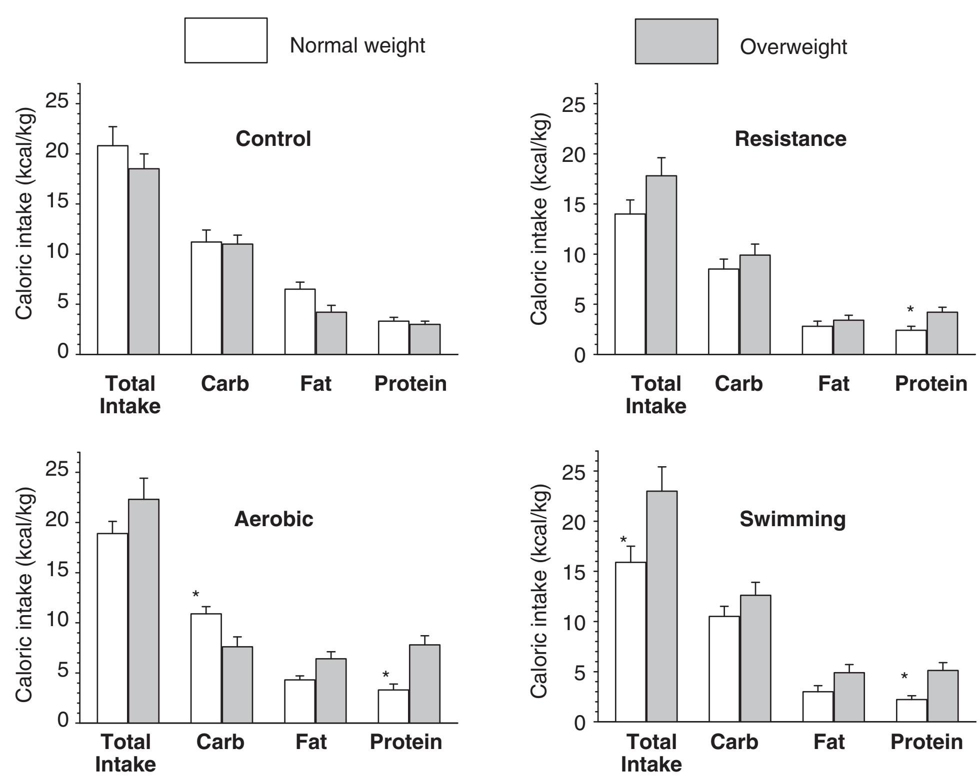
any of the four sessions. Percent time spent at heart rate zones (>170, 140–170, 90–140 beats per minute) is presented in II. No differences were found between overweight and normal weight children in the percent time spent at each heart rate zone during the three different types of exercise sessions. In order to better estimate the energy expenditure in our study, we reviewed the exercise logs and some video movies that were filmed during the study, and calculated the energy expenditure based on the established tables (14).

In both groups the aerobic exercise training session was composed of 15 min of fast running games (~12 km/h), 25 min of group games, such as soccer, 10 minutes of light running (~8 km/h) and 10 minutes of stretching/warm up and cool down. In the normal weight children the calculated energy expenditure was 10.2 kcal/kg body weight/per session, and 9.6 kcal/kg body weight/per session in the overweight children.

The swimming training was composed of 30 min of breast stroke swimming/swimming drills, 20 min of water running games, and 10 minutes of stretching/warm up and cool down. In the normal weight children the calculated energy expenditure was 8.1 kcal/kg body weight/per session, and 7.6 kcal/kg body weight/per session in the overweight children.

The resistance training session was composed of 30 min of circuit training, 20 min of calisthenics, and 10 minutes of stretching/warm up and cool down. In the normal weight children the calculated energy expenditure was 6.9 kcal/kg body weight/per session, and 6.3 kcal/kg body weight/per session in the overweight children.

Following the control session the total energy intake was significantly greater in overweight compared with



*p<0.05 compared with the control (no exercise) session.

Figure 2. Energy intake and the relative contribution from carbohydrate (carb), fat and protein during the control session (no exercise), resistance, aerobic exercise and swimming in the normal weight and overweight children.

normal weight children (805.6±50.7 [3372.2±212.2] versus 604.7±64.5 [2531.3±270.0] kcal (kJ], in overweight and normal weight children, respectively; $p<0.05$). However, when the total energy intake was normalized to body weight, there was no difference between the groups (Figure 2). There was no significant difference in the amount of calories from carbohydrates, fat and proteins between the groups after normalization to body weight (Figure 2).

Following the resistance exercise session the total energy intake was significantly greater in the overweight compared with the normal weight children (779.1±84.3 [3261.3±352.9] versus 435.9±41.8 [1824.7±175.0] kcal [kJ], in overweight and normal weight children, respectively; $p<0.005$). However, when the total energy intake was normalized to body weight, again, there was no significant difference between the groups (Figure 2). The amount of calories from proteins normalized to body weight was significantly greater among the overweight children ($p<0.001$, Figure 2). There was no significant difference in the amount of calories from carbohydrates, and fat between groups (Figure 2).

Following the aerobic exercise session the total energy intake was significantly greater in the overweight compared with the normal weight children (935.3±81.5 [3915.2±341.2] versus 579.3±34.1 [2424.9±142.7] kcal [kJ], respectively; $p<0.005$). However, when the total energy intake was normalized to body weight, there was no difference between the groups (Figure 2). Normalized to body weight, the number of calories from protein was significantly greater ($p<0.002$), and the number of calories from carbohydrates was significantly lower among the overweight children ($p<0.05$, Figure 2). There was no difference in the amount of calories from fat between the groups (Figure 2).

Following the swimming exercise session the total energy intake was significantly greater in the overweight compared with the normal weight children (990.4±105.7 [4145.8±442.5] versus 484.9±44.4 [2029.8±185.9] kcal [kJ], respectively; $p<0.005$). The total energy intake was also significantly greater among the overweight children after normalization to body weight ($p<0.04$, Figure 2). The amount of calories from proteins normalized to body weight was significantly greater among the overweight children ($p<0.007$, Figure 2). There was no significant difference in the amount of calories from carbohydrates, and fat between the groups (Figure 2).

The effect of different types of exercise on total energy intake (normalized to body weight) in the normal weight children is shown in Figure 3. Total energy intake was reduced following exercise compared with the control session; however, only the decrease following resistance training was statistically significant ($p<0.008$). There was a significant decrease in the relative consumption of fat following resistance exercise ($p<0.003$), aerobic exercise ($p<0.03$), and swimming ($p<0.003$) (Figure 4). There was a significant increase in the relative consumption of carbohydrate following the resistance exercise and the swimming practice ($p<0.04$, $p<0.006$, respectively). Compared with the control session, 13 normal weight children (59%) decreased their energy intake following swimming, 11 (50%) decreased their energy intake following the aerobic training session and 16 (73%) decreased their energy intake following the resistance training session.

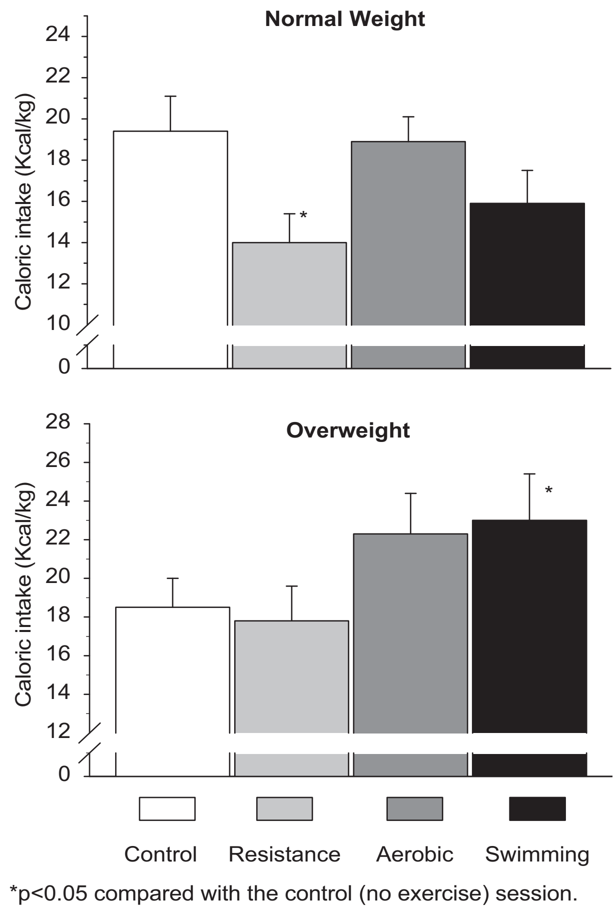


Figure 3. Total energy intake normalized to body weight following different types of exercise in normal weight and overweight children.

The effect of different types of exercise on total energy intake (normalized to body weight) in the overweight children is shown in Figure 3. Total energy intake was increased following exercise compared with the control session; however, only the increase following the swimming training was statistically significant ($p<0.02$). There was a significant increase in the relative consumption of protein following resistance exercise, aerobic exercise and swimming ($p<0.0005$, $p<0.0002$, $p<0.02$, respectively). There was a significant decrease in the relative consumption of carbohy-

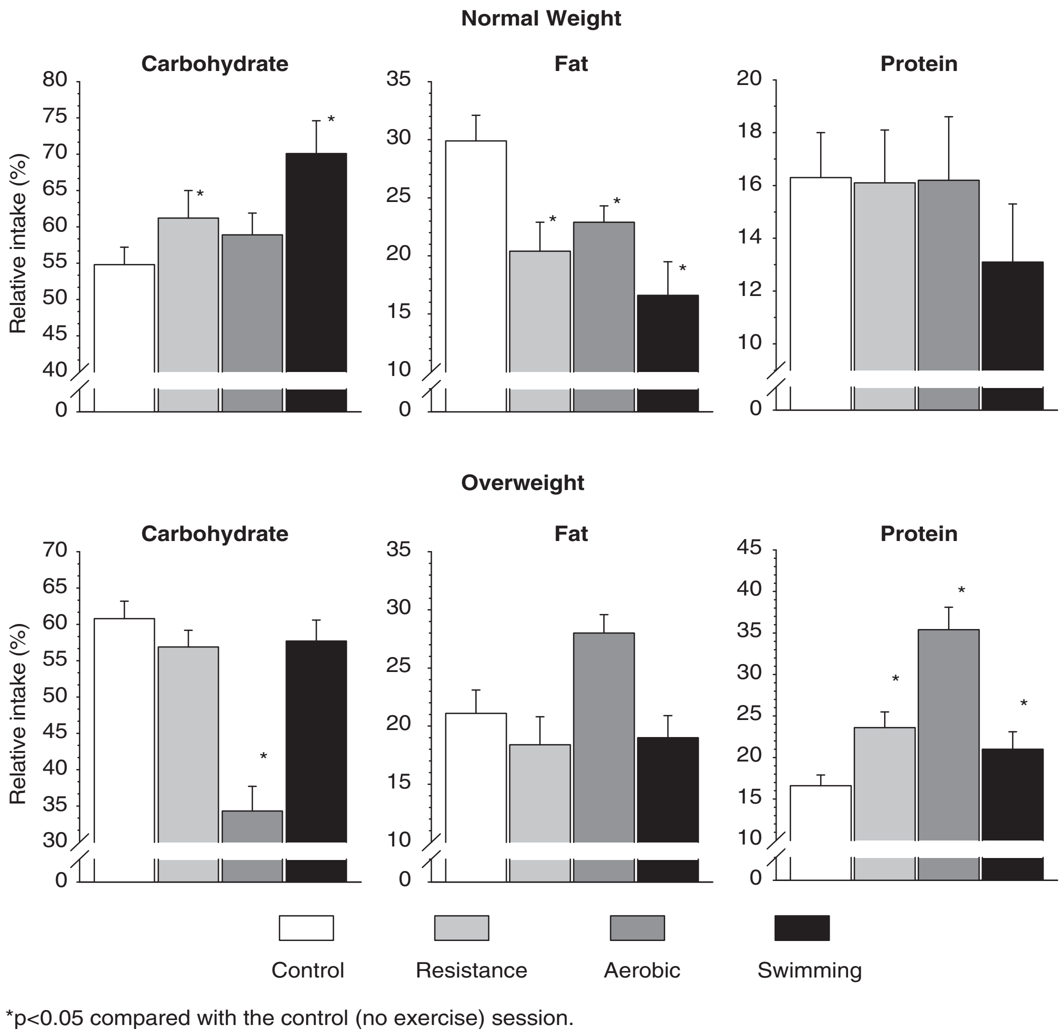


Figure 4. The relative consumption of carbohydrate, fat and proteins (expressed as % of energy intake) following the different types of exercise in the normal weight and overweight children.

drate following the aerobic exercise ($p<0.0003$). Compared with the control session, 16 overweight children (73%) increased their energy intake following swimming, 15 (68%) increased their energy intake following the aerobic training session and 8 (36%) increased their energy intake following the resistance training session.

Using the Chi-square test we found that in both the swimming (14/22 vs. 7/22, $p<0.002$) and aerobic practices (14/22 vs. 9/22, $p<0.03$), but not in the resistance practice, a bigger than 5% increase in caloric intake per kg body weight was observed in more participants from the overweight compared with normal weight group, respectively.

Discussion

Very little is known about the relationship between exercise and food and macronutrient preferences in children, and in particular in overweight and obese children. We found that the immediate effect of exercise on macronutrient choices differ significantly between normal weight and overweight pre-pubertal children. As hypothesized, total energy intake was reduced following resistance-type exercise in the normal weight children. Moreover, the different types of exercise were associated with increased relative consumption of carbohydrate and decreased consumption of fat in the normal weight children. In contrast, overweight children significantly increased their energy intake following the swimming exercise session. All types of exercise (i.e., resistance, aerobic and swimming) lead to a significant increase in the relative consumption of proteins in the overweight children. Finally, the total energy intake was significantly greater in the overweight children following the control (i.e., no exercise), and all types of exercise sessions. After normalization of the total energy intake to body mass, this difference remained significant only following the swimming practice.

The mechanisms responsible for the difference in macronutrient consumption and preference immediately following exercise in normal weight and overweight or obese children are not clearly understood. We believe that the increased energy and protein intake in the obese children, whose fitness levels are generally lower than normal weight children (15), cannot be attributed to a smaller magnitude of the exercise stress. Although accelerometery, oxygen consumption measurements, circulating lactate levels or RPE measurements were not determined in the present study, the similar mean heart rate (Figure 1) and the equal time spent at different heart rate zones during the different exercise sessions suggests that the relative intensity of the exercise in each session were comparable in the two groups. This is relevant because when work is performed at high intensity (e.g., above the subjects anaerobic threshold), relatively small changes in exercise input can lead to large differences in the response of hormones, such as growth hormone and catecholamines (16), that may affect energy intake and food preferences.

In addition, both the normal weight and the overweight children were served the exact same buffet lunch after each session. Therefore, the differences in macronutrient consumption and preferences between the groups cannot be attributed to differences of food supply and/or serving.

Consistent with our hypothesis, energy intake was reduced following exercise in the normal weight children. This decrease was statistically significant only after the resistance-type exercise session (Figure 3). Moreover, exercise was associated with increased consumption of carbohydrate and decreased consumption of fat in the normal weight children (Figure 4). The decrease in energy intake, decreased fat consumption and increased carbohydrate intake immediately after exercise may be explained by several mechanisms (not evaluated in our study). Exercise leads to increased lactate levels, this exercise associated lactate increase leads to a decrease in appetite and energy intake immediately after exercise (17). Exercise also leads to an increase in counter-regulatory hormones, such as catecholamines, growth hormone and corticosteroids, that also reduce appetite immediately after exercise (18). Elevated levels of these hormones enhance glycogenolisis and as a consequence lead to increased desire for carbohydrate consumption in order to reload the glycogen energetic stores. The increase in the counter-regulatory hormones combined with the reduction in insulin levels that occur during exercise leads to a release of free fatty acids, which inhibits appetite and the immediate desire for fat intake and leads to an increase of carbohydrate intake (19). Finally, an exercise associated increase in dopamine level may also reduce appetite, decrease the desire for fat and increase the desire for carbohydrate (20).

Several animal studies supported these theories and showed that exercise leads to a significant increase of carbohydrate consumption and to a significant decrease of fat intake (21,22). In contrast to the relative consistent effect of exercise on food consumption and preferences in animal studies, human studies have shown inconsistency. Verger et al. demonstrated an increase in energy intake following exercise in a group of adult men compared with a group of adults who were involved in sedentary activity (23). In contrast, Klausen et al. reported an increase in energy intake after an intense exercise bout compared with moderate activity (24), with no effect of gender and/or age. These differences in the human studies probably reflect differences in the research design, exercise protocols, the characteristics of the population investigated (e.g., lean versus obese), the fitness level of the participants, the timing, composition and style of the meals and serving etc.

In contrast to our hypothesis, and to the findings in normal weight children, in the overweight children, exercise was associated with an increase in total energy intake following the swimming exercise session. It is a popular belief that swimming stimulates appetite and energy intake, and our results indeed support this notion. Although high adiposity makes floating easier and may lead to less energy expenditure in overweight children, we found that energy intake was significantly greater in the overweight compared with the normal weight children even after normalization to body weight (Figure 2). This suggests that swimming is probably the least favorable exercise choice in order to achieve the target of negative energy balance and to reduce body weight in obese children.

The increase in energy intake in the overweight children was mainly due to a significant increase in protein consumption following each of the exercise sessions. The mechanism for the differences between normal weight and overweight children and for the post-exercise increase in energy and protein intake in obese children is not known. However, we previously demonstrated that the growth hormone and catecholamine response to exercise is attenuated and the dopamine response is almost completely blunted in obese compared with normal weight children and adolescents (25). Therefore, we can only hypothesize that the blunted growth hormone and catecholamine response and the absence of dopamine response to exercise lead to reduced carbohydrate and fat utilization during exercise (26,27), and as a result to a greater protein utilization (28). Increased protein utilization may explain why previous resistance training studies in children demonstrated that elevated BMI was associated with reduced training effect on muscle mass and strength (29). This may explain why in the obese children appetite was not suppressed following exercise, and protein intake was increased immediately after all types of exercise.

It is important to note that although temperature may affect appetite, the weather conditions in both outdoor practices and indoor swimming (including water temperature) were relatively comfortable and similar for both the normal and overweight children. Accurate core temperature was not determined because measurement requires rectal or esophageal probes or a core temperature pill, and this was not feasible in the present study especially in children exercising in a "real life" setting (field, pool etc.).

It is important to point out; however, that the present study only tested the *immediate* effect of a single exercise bout on macronutrient intake and preferences. It is possible that the different exercise types have later effects as well, or that both the normal weight and the obese children compensate for these immediate effects during the rest of the day. The longer effect of the single exercise on food and macronutrient consumption and preferences has yet to be studied.

In summary, although our sample size is relatively small and may not be generalizable to the population, our data suggests that macronutrient intake and preferences in response to exercise are different in normal weight and obese children. Normal weight children decrease their total energy intake and fat consumption and increase their carbohydrate intake, while overweight children increase their total energy and protein intake, in particularly following swimming. Understanding the complicated relationship between different types of exercise, appetite and food choices may help us to optimize exercise training interventions for this unique population, and to select the best exercise protocols to achieve the desired energy balance. Further studies are needed to explore the longer effect of a single exercise and the effect of exercise training interventions on appetite and food choices in children, and in particular in obese children.

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Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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