Appetite, energy intake and food reward responses to an acute High Intensity Interval Exercise in adolescents with obesity

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Abstract

Background. High Intensity Interval Exercise (HIIE) is currently advocated for its beneficial effect on body composition and cardio-metabolic health in children and adolescents with obesity; however its impact on appetite control and food intake remains unknown. The aim of the present study was to examine the effect of a single HIIE session on subsequent energy intake, appetite feelings and food reward in adolescents with obesity.

Methods. Using a randomized cross-over design, *ad libitum* energy intake, subjective appetite, and food reward were examined in 33 adolescents with obesity (13.0 (± 0.9) years) following an acute high-intensity interval exercise (HIIE) versus a rest condition (CON). Absolute and relative energy intakes were measured from an *ad libitum* lunch meal 30 minutes after exercise or rest. Food reward was assessed using the Leeds Food Preference Questionnaire before and after the test meal. Appetite feelings were assessed using visual analogue scales at regular intervals throughout the day.

Results. *Ad libitum* food intake was significantly reduced after HIIE (lunch meal: -7 (± 23.7)%; p=0.014 and whole day: -4 (± 14.7)%; p=0.044), despite unchanged appetite feelings. HIIE was also found to decrease *ad libitum* meal food reward in adolescents with obesity: fat relative preference (from 3.3 (± 9.5) to 0.1 (± 8.0); p=0.03), sweet taste relative preference (from -0.8 (± 13.9) to -5.0 (± 11.8); p=0.02) and fat implicit wanting (from 22.3 (± 55.7) to -13.2 (± 58.5); p=0.01) were significantly decreased in response to the *ad libitum* meal on HIIE. When considering the degree of obesity, it appears that the adolescents with higher BMI and higher fat mass percentage showed greater food intake reductions in response to HIIE (-21 (± 15)% for the third BMI tertile *versus* +8 (± 30)% for the first BMI tertile p=0.004; -15 (± 21)% for the third fat mass tertile *versus* +8 (± 28)% for the first fat mass tertile p=0.017).

Conclusion. A single HIIE session resulted in reduced subsequent energy intake and food reward in adolescents with obesity. Our results also seem to indicate that these nutritional responses depend on the adolescents' degree of obesity with a greater anorexigenic effect observed with higher obesity.

Key words. High Intensity Interval Exercise; Appetite; Energy Intake, Pediatric Obesity

1. Introduction

There is an alarming progression of pediatric obesity with one out of four children concerned in European countries [1]. This obesity pandemic results in part from an energy imbalance between energy intake and expenditure, favored by the increasing availability of palatable high-fat food, concomitantly with a clear decline in children's physical activity and progression of the time they spend sedentary [2]. Anti-obesity strategies that consider both sides of energy balance are therefore needed.

Evidence has shown that exercise energy expenditure and energy intake are loosely coupled variables, therefore we need a better understanding of their interactions [3]. Since the 1950s, many works have attempted to assess the role of daily activity-induced energy expenditure (from vigorous physical activity to sedentary behaviors) on energy intake in adults [4]. A recent systematic review in adults revealed there to be a better control of energy intake in active compared to inactive people, while individuals with very low levels of physical activity and high rates of sedentary behavior seem to suffer from a non-regulated control of food intake [5].

Although this relationship between exercise and energy intake has been mainly studied in adults for the last couple of decades, more attention has been recently paid to this question among children and adolescents, lean or obese [6]–[8]. According to the available evidence, while an acute bout of exercise does not seem to alter subsequent food consumption in lean children and adolescents [9], [10], an acute bout of intensive exercise (above 70% of the adolescent's maximal capacities) has been shown to significantly decrease food intake at the following meal in those with obesity [11]. This effect has been attributed to higher post-exercise anorexigenic gastrointestinal peptide concentrations [12] (such as peptide YY, glucagon-like peptide-1, and pancreatic polypeptide) and lower neurocognitive responses to food cues [13].

High-Intensity Interval Exercise (HIIE) has recently been described as an efficient exercise modality in adolescents with obesity, producing a lower perceived exertion and being at least as effective as moderate-continuous training to improve their body composition and metabolic profile [14]. Recent studies conducted in overweight adults also suggest that HIIE has similar effects on appetite sensations and hedonic liking and wanting for food than moderate intensity interval training [15]. Thus, HIIE does not appear to lead to a reward-induced increase in food intake [15]. The same team also found that a 4-week HIIE intervention was able to reduce hunger and the desire to eat, as well as to limit food compensation compared to a moderate-intensity program that tended to increase the preference for high fat food in overweight adults [16]. To our knowledge, there is so far no study that has examined the effect of HIIE on subsequent energy intake and appetite feelings in children and adolescents with obesity. Morris and collaborators recently examined the effect of a 22-minute HIIE session composed of 30-second sprints on subsequent food intake in 10-year-old lean children [17]. According to their results, food intake and macronutrient preferences at the following meal were not affected, which is consistent with previous results from our teams showing that only overweight and obese youth modify their food consumption after an intensive bout of exercise [7].

The aim of the present study was to examine the effect of a single HIIE session on subsequent energy intake, macronutrient consumption, appetite sensations and food reward in adolescents with obesity. Secondly, we questioned whether these post-exercise nutritional adaptations could be influenced by the degree of obesity in adolescents.

2. Methods

2.1. Population

Thirty three adolescents with obesity (according to Cole et al. [18]) aged 12-15 years old (Tanner stage 3-4) participated in this study (12 boys and 21 girls). The adolescents were recruited through the local Pediatric Obesity Center (Tza Nou, La Bourboule, France). The adolescents and their parents were proposed to participate by the pediatrician during their regular medical visit in the center. To be included in the study, participants had to be free of any medication that could interact with the protocol (e.g. diabetic or blood pressure medications), should not present any contraindications to physical activity, and had to take part in less than 2 hours of physical activity per week (according to the International Physical Activity Questionnaire –IPAQ [19]). This study was conducted in accordance with the Helsinki declaration and all the adolescents and their legal representative received information sheets and signed up consent forms as requested by the local ethical authorities (Human Ethical Committee (CPP Sud Est VI) authorization reference: AU 1178 2015).

2.2. Design

After a preliminary medical inclusion visit made by a pediatrician to control for the ability of the adolescents to complete the study, they were asked to perform a maximal aerobic test and their body composition was assessed by Dual-energy X-ray Absorptiometry (DXA). The adolescents were then asked to complete a food preference questionnaire and the Three-Factor-Eating-Questionnaire R21 [20] in order to exclude children with high cognitive restraint. Afterward, adolescents were randomly assigned to one of two experimental sessions performed one week apart: i) a rest condition without exercise (CON); ii) a High Intensity Interval Exercise condition (HIIE). On the two occasions, participants received a standardized breakfast (08:30) and started one of the two experimental conditions at 11:15

am (rest or exercise). Thirty minutes after the end of the experimental conditions (rest or exercise), participants had to complete the Leeds Food Preference Questionnaire (LFPQ) [21] before being served with an ad libitum buffet-style meal. They had to complete the LFPQ once more after the meal. Dinner energy intake was also assessed using an ad libitum buffet-style meal. Their appetite sensations were assessed at regular intervals through the day. Outside the experimental conditions and between the two *ad libitum* test meals, the adolescents were requested not to engage in any moderate to vigorous physical activity and mainly completed sedentary activities such as reading, homework or board games.

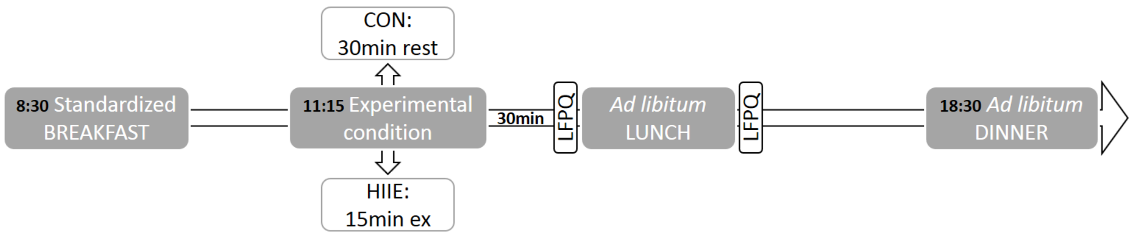

Figure1. Design of the experimental days. **CON: rest condition; HIIE: high intensity interval exercise; LFPQ: Leeds Foos Preferences Questionnaire**

2.3. Anthropometric characteristics and body composition

Adolescents were weighed and had height measured wearing light clothing while bare-footed, using respectively a digital scale and a standard wall-mounted stadiometer. Body Mass Index (BMI) was calculated as weight (kg) divided by height squared (m^2). Afterwards, BMI was calculated in the sex and age dependent French reference curves to obtain the BMI percentile [22]. Fat mass (FM) and fat-free mass (FFM) were assessed by dual-energy X-ray absorptiometry (DXA) following standardized procedures (QDR4500A scanner, Hologic, Waltham, MA, USA). These measurements were obtained during the preliminary visit by a trained technician.

2.4. Maximal oxygen uptake test (VO2)

Each subject performed a $\dot{V}O2$peak test on a traditional concentric ergometer [23]. The initial power was set at 30W during 3 minutes, followed by a 15W increment every minute until exhaustion. The adolescents were strongly encouraged by the experimenters throughout the test to perform their maximal effort. Maximal criteria were: heart rate >90% of the theoretical maximum heart rate (210 – 0.65 × age), Respiratory Exchange Ratio (RER = $\dot{V}CO2/\dot{V}O2$) > 1.1 and/or $\dot{V}O2$ plateau. Cardiac electrical activity (Ultima SeriesTM, Saint Paul, MN) and heart rate (Polar V800) were monitored and the test was coupled with a measurement of gas exchanges breath by breath (BreezeSuite Software, Saint Paul, MN), that determined $\dot{V}O_2$ and CO_2 (Carbon Dioxide) production ($\dot{V}CO_2$). Volumes and gases were calibrated before each test. The $\dot{V}O_2$peak was defined as the average of the last 30 s of exercise before exhaustion.

2.5. Experimental conditions

Rest condition (CON): between 11:15 to 11:45 am, the participants remained seated on a comfortable chair (30 minutes). They were not allowed to talk, read, watch TV or to complete any intellectual tasks.

Exercise condition (HIIE): between 11:15 to 11:45 am, the participants were invited to perform a High Intensity Interval Exercise on an ergo-cycle, for a total duration of 15 minutes. Warming-up began at 60% of Maximal Heart Rate (HRmax) for 3 minutes. Then, adolescents had to perform 5 times the same pattern: 2 minutes intense bouts interspersed by active 30 seconds low intensity cycling. The intensity of the steps was as follows: 70%, 75%, 80%, 85%, and 90% HRmax. The intensity was controlled by heart rate records (Polar V800) using the results from the maximal aerobic capacity testing. Exercise induced energy expenditure was estimated afterwards based on the results obtained during the maximal oxygen uptake evaluation.

2.6. Perceived exertion

Immediately after exercise (HIIE session), the adolescents were asked to rate their perceived exertion using the Children’s Effort Rating Table (CERT) from Williams et al. [24]. This scale was elaborated using a range of items from 1 to 10, the number 1 corresponding to an extremely easy exercise, while an effort leading the subject to interrupt the test because of its hard difficulty is indicated by 10.

2.7. Energy intake

At 08:00am, the adolescents consumed a standardized calibrated breakfast (500kcal) respecting the recommendations for their age (composition: bread, butter, marmalade, yoghurt or semi-skimmed milk, fruit or fruit juice). Lunch and dinner meals were served *ad libitum* using a buffet-type meal. The content of the buffets was determined based on the adolescent’s food preferences and eating habits. Top rated items as well as disliked ones and items liked but not usually consumed were excluded to avoid over-, under- and occasional consumption. Lunch menu was beef steak, pasta, mustard, cheese, yogurt, compote, fruits and bread. Dinner menu was ham/turkey, beans, mashed potato, cheese, yogurt, compote, fruits and bread. Adolescents were told to eat until feeling comfortably satiated. Food items were presented in abundance. Food intake was weighted by the experimenters and the macro nutritive distribution (proportion of fat, carbohydrate and protein) as well as the total energy consumption in kcal were calculated using the software Bilnut 4.0. This methodology has been previously validated and published [25].

2.8. Subjective appetite sensations

Appetite sensations were collected throughout the day using visual analogue scales (150 millimeters scales) [26]. Adolescents had to report their hunger, fullness, desire to eat and prospective food consumption at 12 time points (before and immediately after breakfast, 30 minutes and 60 minutes after breakfast, prior and after the experimental condition (CON or HIIE), before and immediately after lunch, 30 minutes and 60 minutes after lunch, before and right after dinner). The questions were i) "How hungry do you feel?", ii) "How full do you feel?", iii) "Would you like to eat something?", iv) "How much do you think you can eat?".

2.9. Food liking and wanting

The Leeds Food Preference Questionnaire (described in greater methodological detail by Dalton and Finlayson [27]) provided measures of food preference and food reward. Participants were presented with an array of pictures of individual food items common in the diet. Foods in the array were chosen by the local research team from a validated database to be either predominantly high (>50% energy) or low (<20% energy) in fat but similar in familiarity, protein content, palatability and suitable for the study population. The LFPQ has been deployed in a range of research [27] including a recent exercise/appetite trial in young French males [28]. Explicit liking and explicit wanting were measured by participants rating the extent to which they like each food ("How pleasant would it be to taste this food now?") and want each food ("How much do you want to eat this food now ?"). The food images were presented individually, in a randomized order and participants make their ratings using a 100-mm VAS. Implicit wanting and relative food preference were assessed using a forced choice methodology in which the food images were paired so that every image from each of the four food types was compared to every other type over 96 trials (food pairs). Participants were instructed to respond as quickly and accurately as they could to indicate the food they want to eat the most at that time ("Which food do you most want to eat now?"). To measure implicit wanting, reaction times for all responses were covertly recorded and used to compute mean response times for each food type after adjusting for frequency of selection. Responses on the LFPQ were used to compute mean scores for high fat, low fat, sweet or savoury food types (and different fat-taste combinations).

2.10. Statistical analysis

Sample size was determined according to previous works reported in literature [11] and to an estimation based on effect-size difference greater than 0.6, for a two-sided type I error at 5%, a statistical power at 90% and a correlation coefficient at 0.5 (two conditions for a same subject). For these assumptions, 32 subjects were enough to detect such true difference between the two conditions where our recruitment enrolled 33 subjects. Statistical analysis was performed using Stata software (version 13; StataCorp, College Station, Texas, USA) and Statview (version 4 for Windows). Continuous data were expressed as mean (± standard deviation (SD)). All tests were two-sided, with a Type I error set at 0.05. The normality of the data was checked using the Smirnov-Kolmogorov test. Adapted paired T-tests were used to compare absolute and relative energy intake, macronutrient preferences and energy expenditure between conditions (CON and HIIE). For appetite sensations, area under the curves (AUC, based on the trapezoid methods) were calculated and compared between CON and HIIE using T-test. To measure the *ad libitum* meal effect on relative preference, implicit wanting, explicit wanting and explicit liking, statistical analysis was conducted with linear mixed models to take into account the repeated measurements per subject. Interaction between time (before and after meal) and condition (CON and HIIE) was tested before performing subgroup analyzes. Our sub-analysis, questioning the effect of degree of obesity, children were classified in tertiles (based on weight, BMI, FM% and FFM kg as the main anthropometric and body composition indicators used in the literature to characterize obesity). One-way ANOVA were used to compare lunch energy intake, macronutrient preferences, and appetite sensations AUC on CON and HIIE between tertiles. Bonferroni post-hoc test were used when appropriate.).

3. Results

3.1. Characteristics of the participants

Thirty-three healthy adolescents with obesity were recruited for this study (11 boys, 21 girls). Participants had an average (± SD) age of 13.3 (± 0.9) years; weight: 93.2 (± 13.0) kg; BMI: 35.0 (± 4.3) kg/m^2; z-BMI: 2.3 (± 0.2); fat mass: 37.6 (± 3.5)%; fat free mass: 55.9 (± 7.3) kg and VO2peak: 23.5 (± 4.3) ml/min/kg.

3.2. *Characteristics of HIIE and CON condition*

Energy expenditure (EE) induced by exercise (total duration 15 minutes) was significantly higher compared to the 30-minute resting energy expenditure (respectively 102 (± 21) kcal; and 52 (± 10) kcal; p<0.001). The rate of perceived exertion by the end of the HIIE was 5.8 (± 2.0).

3.3. *Energy intake*

Absolute energy intake (EI) at lunch (HIIE: 1102 (± 276) kcal and CON: 1222 (± 310) kcal; p=0.014; which represents a difference of 7%), as well as the total energy intake over the day (HIIE: 2062 (± 460) kcal and CON: 2177 (± 471) kcal; p=0.044; which represents 4% difference) were significantly lower on HIIE compared with CON. Moreover, relative energy intake after lunchtime (REI = EI-EE) was also lower on HIIE compared with CON (1005 (± 274) kcal and 1172 (± 306) kcal respectively; p=0.001) (Table1).

Table1. Energy expenditure, energy intake and relative energy intake, in response to high intensity interval exercise (HIIE condition) or rest (CON condition), in obese adolescents.

	CON Mean (± SD)	**HIIE** Mean (± SD)	***p* value**
Lunch EI (kcal)	1222 (± 310)	1102 (± 276)	**0.014**
Lunch REI (kcal)	1172(± 306)	1005 (± 274)	**0.001**
Dinner EI (kcal)	955 (± 228)	960 (± 246)	0.877
Total EI (kcal)	2177 (± 471)	2062 (± 460)	**0.044**

CON: control condition; HIIE: high intensity interval exercise; EI: energy intake; REI: relative energy intake (EI-EE); SD: Standard Deviation; *: p<0.05; **: p<0.01; ***: p<0.001, NS: not significant

3.4. *Macronutrient consumption*

The macronutrient intake expressed as both absolute intake (grams) and percentage of the total ingested energy, is shown in Table2. On HIIE, the adolescents consumed significantly less protein and fat (in grams) at lunch compared to CON (p=0.008 and p=0.022). This difference is still significant regarding the total protein and fat content of the food consumed all day (p=0.020 and p=0.033). The carbohydrate consumption at lunch tended to decrease on HIIE compared with CON (p=0.058).

Table2. Absolute (grams) and relative (percentages) macronutrient consumption between meals during each experimental condition.

	CON		HIIE		***p* value**	
	Grams Mean (± SD)	% Mean (± SD)	Grams Mean (± SD)	% Mean (± SD)	Grams	%
Lunch protein	**64.3** (± 13.0)	21.4 (±2.3)	**58.6** (± 13.0)	21.5 (± 2.5)	**0.008**	0.801
Dinner protein	57.1 (± 15.8)	24.3 (± 6.2)	56.5 (± 14.5)	24.3 (± 6.2)	0.782	0.948
Total protein	**121.4** (± 22.9)	22.6 (± 3.4)	**115.1** (± 23.1)	22.7 (± 3.3)	**0.020**	0.994
Lunch fat	**45.60** (± 9.6)	34.7 (± 8.6)	**41.6** (± 9.8)	34.6 (± 6.0)	**0.022**	0.947
Dinner fat	33.5 (± 18.7)	30.2 (± 12.1)	32.0 (± 17.8)	28.3 (± 11.0)	0.430	0.120
Total fat	**79.5** (± 22.5)	32.7 (± 6.1)	**73.6** (± 22.7)	31.9 (± 5.9)	**0.033**	0.384
Lunch CHO	139.6 (± 54.8)	44.5 (± 8.0)	124.7 (± 47.5)	44.4 (± 8.9)	**0.058**	0.947
Dinner CHO	107.9 (± 29.4)	46.2 (± 11.7)	113.0 (± 29.9)	48.0 (± 9.9)	0.376	0.265
Total CHO	247.5 (± 70.7)	45.3 (± 7.1)	237.8 (± 66.7)	46.1 (± 7.03)	0.308	0.499

CON: control condition; HIIE: high intensity interval exercise; CHO: Carbohydrate; NS: not significant; SD: Standard Deviation.

235 *3.5. Subjective appetite sensations*

Overall daily hunger, satiety, desire to eat and prospective food consumption were not different between conditions as illustrated by Figure2.

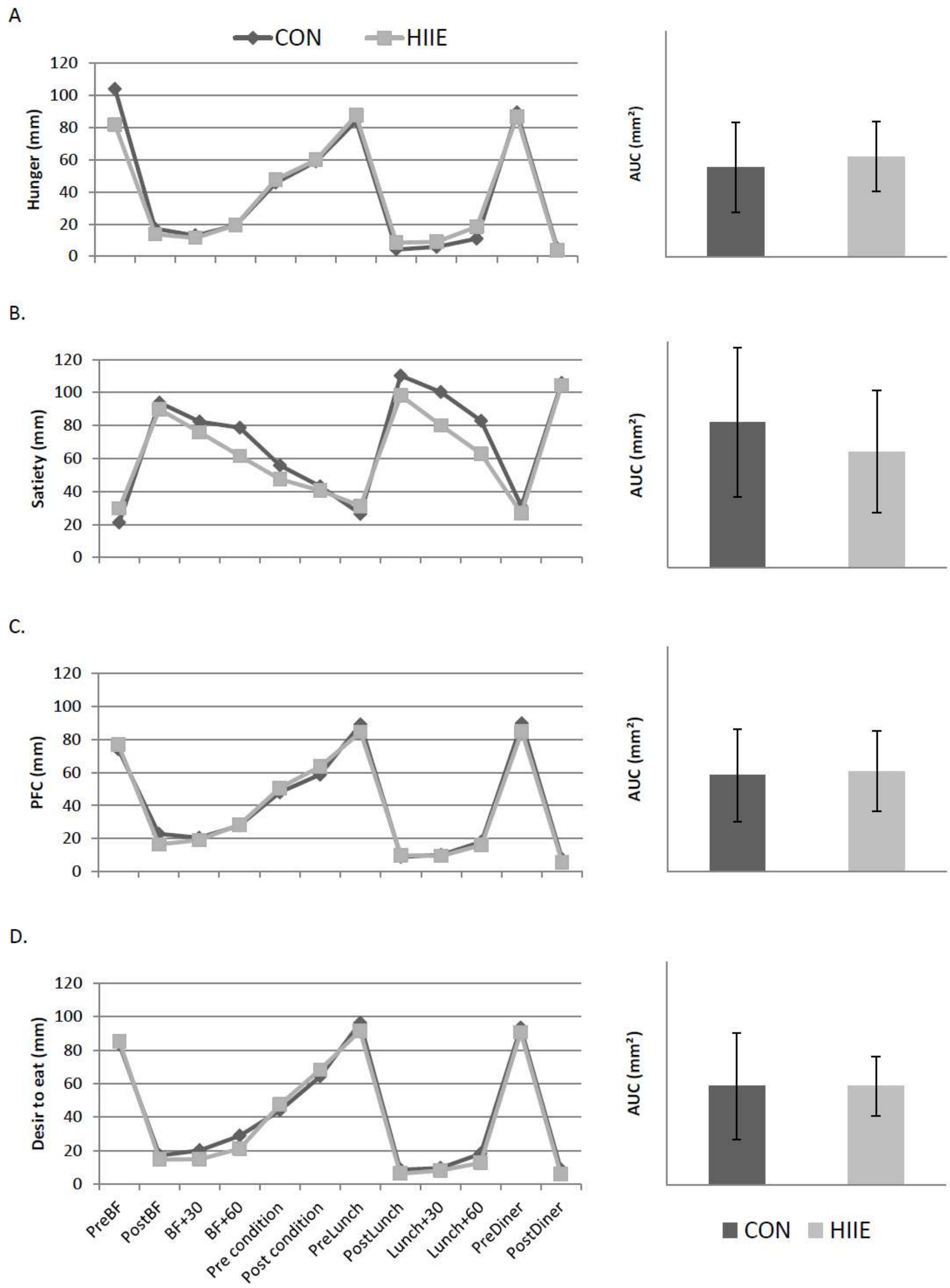

Figure2. Subjective Hunger (A), Satiety (B), Prospective Food Consumption (C) and Desire to Eat (D) kinetics (left side) and Area Under the Curve (AUC, right side). **CON: rest condition; HIIE: high intensity interval exercise; AUC: area under the curves.**

3.6. Food reward

Our results show a significant meal x condition interaction for taste implicit wanting (p=0.046) with sweet taste implicit wanting increasing after the *ad libitum* meal on CON while decreasing on HIIE (see Table3: a positive score for fat and/or taste biais indicates a preference for high fat and/or sweet food; a negative score for fat and/or taste biais indicates a preference for low fat and/or savoury food). The before meal LFPQ results were not different after the rest or the HIIE condition. However, whereas no meal effect on CON was observed; fat relative preference, sweet taste relative preference and fat implicit wanting significantly decrease in response to the *ad libitum* meal on HIIE (p=0.026, p=0.013 and p=0.010 respectively).

Table3. Relative preference, implicit wanting, explicit wanting and explicit liking for high *vs* low fat foods and sweet *vs* savory foods, between rest and exercise condition.

			CON Mean (± SD)	**Time**	**HIIE Mean (± SD)**	**Time**	**Condition**	**Interaction time * condition**
Relative preference	**Fat biais**	Before	4.1 (± 9.7)	0.101	**3.3 (± 9.5)**	**0.026**	0.729	0.814
		After	1.2 (± 8.2)		**0.1 (± 8.0)**			
	Taste biais	Before	-3.9 (± 13.3)	0.839	**-0.8 (± 13.9)**	**0.013**	0.217	0.092
		After	-3.2 (± 10.9)		**-5.0 (± 11.8)**			
Implicit wanting	**Fat biais**	Before	7.7 (± 28.3)	0.535	**22.3 (± 55.7)**	**0.010**	0.157	0.093
		After	1.2 (± 51.2)		**-13.2 (± 58.5)**			
	Taste biais	Before	**-15.0 (± 42.9)**	0.076	**-5.7 (± 70.6)**	0.203	0.660	**0.046**
		After	**5.1 (± 60.8)**		**-22.6 (± 50.3)**			
Explicit wanting	**Fat biais**	Before	6.2 (± 12.1)	0.238	3.5 (± 15.5)	0.932	0.245	0.461
		After	3.2 (± 9.7)		3.1 (± 12.3)			
	Taste biais	Before	-4.1 (± 12.8)	0.688	-1.7 (± 16.4)	0.304	0.472	0.693
		After	-5.4 (± 14.7)		-4.8 (± 11.1)			
Explicit liking	**Fat biais**	Before	5.0 (± 12.6)	0.104	4.7 (± 14.7)	0.569	0.863	0.472
		After	1.4 (± 10.3)		3.5 (± 12.5)			
	Taste biais	Before	-6.3 (± 12.0)	0.857	-2.2 (± 13.6)	0.174	0.070	0.288
		After	-5.5 (± 15.4)		-5.5 (± 11.8)			

CON: control session; HIIE: high intensity interval exercise; NS: not significant; SD: Standard Deviation

3.7. Effects of the degree of obesity

As detailed in the statistical analysis section, adolescents were classified in tertiles, depending on their degree obesity, according to four categories: weight, BMI, FM% and FFM (Table4).

Table4. Description of the obesity tertiles.

	T1 Mean (± SD)	**T2 Mean (± SD)**	**T3 Mean (± SD)**	***ANOVA***	***Post-hoc***
Weight tertiles	81.00 (± 3.63)	90.48 (± 3.12)	107.13 (± 12.53)	<0.001	T1<T2*; T1<T3***; T2<T3***
BMI tertiles	30.69 (± 1.52)	34.78 (± 0.66)	39.42 (± 3.95)	<0.001	T1<T2<T3***
FM % tertiles	33.65 (± 1.79)	38.01 (± 1.16)	41.13 (± 2.10)	<0.001	T1<T2<T3***
FFM kg tertiles	48.84 (± 2.11)	54.75 (± 1.73)	64.26 (± 5.42)	<0.001	T1<T2<T3***

T1: first tertile; T2: second tertile; T3: third tertile; BMI: Body Mass Index; FM: Fat Mass; FFM; Fat Free Mass; SD: Standard Deviation; *: p=0.015; ***: p<0.001.

Regarding lunch energy intake depending of the degree of obesity, the delta between HIIE and CON was significantly different between the first and third BMI tertiles (ANOVA p=0.013; post-hoc T1 *vs* T3 p=0.004): a 21% lower energy intake (-287 (± 242) kcal) was observed after HIIE compared with CON in adolescents within the third BMI tertile, while those in the first one (then with a lower BMI) increased their food consumption at the lunch test meal by 8% (+33 (± 284) kcal) in response to HIIE. Similar results were observed when using FM% tertiles (ANOVA p=0.033), where lunch food intake was lower in response to the HIIE session in the adolescents of the second and third FM% tertiles only (-15% (-219 (± 283) kcal) for the third FM% tertile and -14% (-189 (± 222) kcal) for the second FM% tertile), while an 8% (+45 (± 225) kcal) increase was observed in the first FM% tertile (T1 *vs* T2: p=0.033; T1 *vs*. T3: p=0.017). The results are illustrated in Figure3.

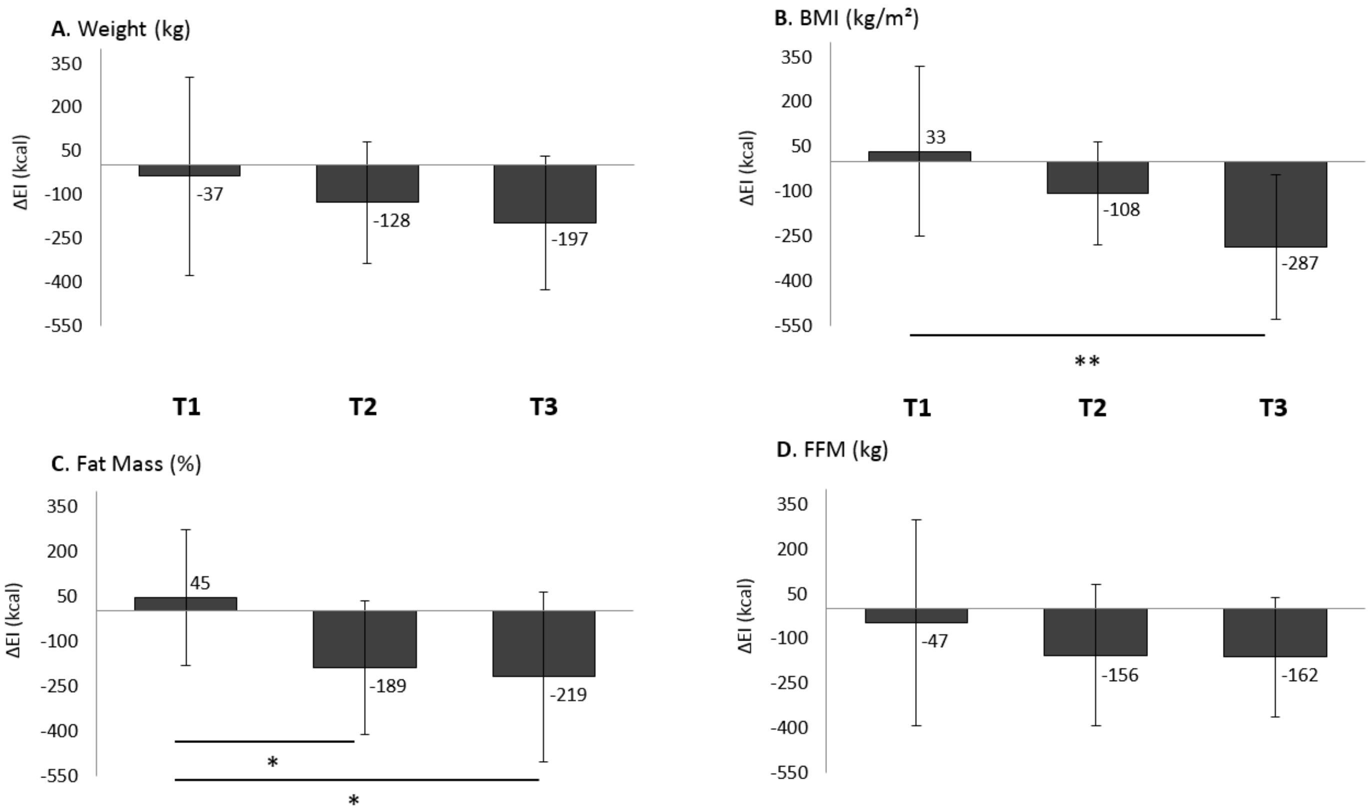

Figure3. Lunch energy intake differences (ΔEI) in response to high intensity interval exercise compare to control session, related to weight (A), body mass index (B), fat mass (C) and fat free mass (D) tertiles. **Δ EI: Energy intake difference between control and high intensity interval exercise session; T1: first tertile; T2: second tertile; T3: third tertile; BMI: Body Mass Index; FM: Fat Mass; FFM; Fat Free Mass; SD: Standard Deviation; *: p<0.05; **: p<0.01**

The macronutrient consumption depending on the tertiles of obesity showed a significant BMI tertiles x conditions interaction on carbohydrate consumption (in grams) (p=0.015): while the first BMI tertile (lower BMI) increased CHO consumption after HIIE compared to CON (+8g), the second and the third BMI tertiles decreased their intake of CHO (-13.2g and -41.4g). For the sensations of appetite, we did not find either any difference between tertiles.

4. Discussion

While HIIE is largely promoted as an efficient anti-obesity strategy thanks to its beneficial effects on body composition and cardio-metabolic health [14], less is known regarding its potential nutritional impacts. The present study examined for the first time the effect of a single HIIE session on subsequent energy intake, macronutrient consumption, appetite sensations and food reward in adolescents with obesity. According to our main result, an acute HIIE session reduced subsequent *ad libitum* food intake (at the following test meal and whole day), despite unchanged appetite feelings in 12-15 years old patients with obesity. HIIE was also found to decrease post *ad libitum* meal food reward in adolescents with obesity. Interestingly these nutritional responses seem to depend on the adolescents' degree of obesity.

Recently, Morris and collaborators explored for the first time the effects of HIIE on food consumption and appetite sensations in children [17]. Contrary to our results, their 22-minutes HIIE session composed of 30-second sprints did not affect subsequent food intake in lean children [17]. Altogether, Morris et al. and our results confirm the actual literature clearly showing that intensive acute exercise can favor reduced energy intake in overweight and obese but not lean children and adolescents [7], [11], [29], [30]. These results add to the available evidence and suggest that HIIE might not only have beneficial effects on body composition, physical and cardio-metabolic fitness, but can also favor a transient negative energy balance, as illustrated by the significantly lower REI observed in the present work, as compared with a rest session. Importantly, this is accompanied by a low rate of perceived exertion, highlighting the acceptability and feasibility of such exercise modality in youth with obesity. While further chronic studies are needed to test the nutritional responses to long term High Intensity Interval Training, the observed transient anorexigenic effect of HIIE can be explained by some physiological and neurocognitive responses. Indeed, as already expressed in the literature, HIIE affects the concentrations of some of the main appetite-related peptides in adolescents with obesity, favoring increased PYY_{3-36} [31] and decreased active ghrelin [29]. Recent data suggest that post-intensive exercise energy intake modifications can also be explained by the response to exercise of some neural networks involved in the cognitive processing of food-related cues. In their work, Fearnbach et al. recently questioned the potential role played by such cognitive processing of food-related cues in the nutritional response to exercise in children and adolescents [13], [32]. Their results showed that the neural response reflecting the cognitive effort engaged in response to food stimuli is significantly reduced compared to non-food ones after a 45-minute cycling exercise set at moderate-to-high intensity in obese, but not lean adolescent boys [13], [32]. Importantly, this reduced neural activation was accompanied by a significant decreased energy intake at the following meal compared to a rest condition [32].

While all the previously published studies in the field have considered weight status, the present analysis also questioned whether the degree of obesity may influence the adolescents' post-exercise energy intake. According to this sub-analysis, the transient anorexigenic effect of exercise seems to be stronger in adolescents with higher BMI and higher fat mass percentage. Indeed, a 21% decreased energy intake was observed after HIIE compared with CON in adolescents within the third BMI tertile, while those in the first one (with a lower BMI) increased their food consumption at the test meal by 8% in response to HIIE. Similar results were observed when using FM% tertiles, where food intake was reduced in response to the HIIE session in the adolescents of the second and third tertiles only (-15% for the third tertile and -14% for the second one), while a 8% increase was observed in the first tertile. These results are consistent with previous works done by Fearnbach et al. who found body composition specific post-exercise neural responses to food cues [13], [33]. According to their results, body weight, BMI and FM are inversely correlated with the neural response to food stimuli following exercising [13]. In other words, they found that a higher index of adiposity was associated with lower brain responsiveness to food stimuli following 45 minutes-cycling exercise (at 65% VO2max). Thus, our results indicating a body composition specific nutritional post-exercise response may be explained by different cognitive processing of food stimuli: the greater post-exercise reduced energy intake in adolescents with the highest degree of obesity could be explained by a reduced neural response to food cues. Our results however failed to show any significant difference between FFM tertiles, which seems contradictory with the actual literature pointing a strong association between lean mass and daily energy intake in both adults and adolescents [34], [35] with Fearnbach et al. moreover showing a positive association between fat-free mass index and post-exercise intake in children at risk for obesity [36].

Interestingly, the reduced food consumption observed in the present work is not due to a particular effect on one specific macronutrient. Indeed, absolute protein, fat and CHO intakes at the test meal were all reduced (tendency for CHO) with no change of their respective contribution to the total energy ingested. Although the literature remains quite divergent regarding the macronutrient response to acute exercise, these results are in line with a recent systematic review suggesting that children and adolescents with obesity do not alter their relative macronutrient composition in response to acute exercise and calling for further specific researches [7]. Our secondary analysis however showed a significant BMI tertiles x CHO consumption interaction, with a higher CHO intake by the adolescents with lower BMI after HIIE while the adolescents of the second and the third BMI tertiles decreased their CHO consumption. More studies are needed regarding the potential effect of body composition on post-exercise macronutrient consumption.

Importantly, the observed post-exercise reduction in energy intake was not accompanied by any change in subjective appetite sensations (feelings of hunger, satiety, prospective food consumption or desire to eat); suggesting that this effect occurs without any food frustration in adolescents. This result is in line with previous works that have already highlighted this uncoupling effect of exercise on energy intake and appetite sensations in children and adolescents [37].

Elsewhere, evidence indicates that exercise may be link to food intake through its potential effect on food reward. If previous works have demonstrated the effect of exercise on explicit and implicit hedonic process in adults [15], [16], [38], [39], the present work is the first to question the effect of acute exercise on food reward in adolescents with obesity. According to our results, implicit wanting for sweet taste decreased in response to the *ad libitum* meal during the HIIE condition, while it increased after the CON condition. Furthermore, the preferences for high fat foods and sweet foods (relative to low fat foods and savory foods) were significantly reduced in response to our *ad libitum* test meal after the acute HIIE condition but not during the rest condition. Similarly, HIIE favored a reduced fat implicit wanting after the *ad libitum* meal compared to the rest condition. Altogether, these results suggest that an acute bout of HIIE might favor reduced reward for fat and sweet foods. These results are in line with previous works that demonstrated that food reward is altered by both aerobic and resistance acute exercises [40]. Indeed, McNeil et al. found greater relative preference for high fat as well as greater explicit wanting for high fat during their CON condition compared to both (aerobic and resistance) exercises. However, Finlayson et al. highlighted high inter-individual food hedonic responses to exercise showing that while some individuals decreased their desire to eat after exercising others increased their implicit wanting [39]. Further studies considering and questioning the inter-individual variability regarding post-exercise food reward are needed in both adults and youth.

The present results have to be interpreted in light of some limitations. First, although our results provide new interesting insights regarding the post-exercise energetic and behavioral adaptations of appetite control, physiological and neurocognitive investigations are missing to provide some potential explanatory mechanisms. Moreover, while acute exercises, particularly intensive ones, have be shown to impact energy balance (intake and expenditure) for up to 72 hours, it would have been useful to assess energy expenditure and intake for the following days. Although the fact that the rest and the exercise conditions are not of exact same duration could be considered as a limitation of the study, the standardization of the timing between the end of both experimental conditions and the LFPQ and *ad libitum* meal (30 minutes after both) has to be highlighted (so that the delay between the experimental conditions and the nutritional evaluations was the same). Furthermore, these results relate to the acute effect of HIIE on appetite control in adolescents with obesity; however, longitudinal investigations should be conducted, since it has been suggested in adults with obesity that four weeks of high intensity interval training might minimize the enhancement of food reward compared with a moderate intensity interval training [16]. Similarly, it must be underlined that our secondary analysis, questioning the effect of the degree of obesity using tertiles, might have been influenced by the fact that all the adolescents received the same breakfast independently of their level of obesity and then basal energy needs, which might have influenced energy intake at the test meal. Importantly, our analysis did not show gender differences, which is in line with previously published studies that have already pointed this absence of gender effect regarding post-exercise energy intake and appetite feelings in adolescents with obesity [40].

5. Conclusion

In conclusion, the present study found that an acute session of HIIE favors reduced subsequent energy intake and food reward despite unchanged appetite feelings in adolescents with obesity. Although this joins up with the actual literature regarding the effect of intensive exercise on subsequent nutritional responses in obese youth, our results seem to indicate for the first time that these nutritional responses depend on the adolescents' degree of obesity with a greater anorexigenic effect observed with higher obesity. Further studies are needed regarding the effects of HIIE on appetite and energy intake in such a population and to better understand this potential role played by the degree of obesity in adolescents.

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