British Journal of Nutrition (2020), 123, 592–600
doi:10.1017/S0007114519003106

Post-moderate-intensity exercise energy replacement does not reduce subsequent appetite and energy intake in adolescents with obesity

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(Submitted 29 July 2019 – Final revision received 7 November 2019 – Accepted 21 November 2019 – First published online 29 November 2019)

Abstract

Exercise modifies energy intake (EI) in adolescents with obesity, but whether this is mediated by the exercise-induced energy deficit remains unknown. The present study examined the effect of exercise with and without dietary replacement of the exercise energy expenditure on appetite, EI and food reward in adolescents with obesity. Fourteen 12–15-year-old adolescents with obesity (eight girls; Tanner 3–4; BMI 34·8 (SD 5·7) kg/m^2; BMI z score 2·3 (SD 0·4)) randomly completed three experimental conditions: (i) rest control (CON); (ii) 30-min cycling (EX) and (iii) 30-min cycling with dietary energy replacement (EX + R). *Ad libitum* EI was assessed at lunch and dinner, and food reward (Leeds Food Preference Questionnaire) before and after lunch. Appetite was assessed at regular intervals. Lunch, evening and total EI (excluding the post-exercise snack in EX – R) were similar across conditions. Lunch and total EI including the post-exercise snack in EX + R were higher in EX – R than CON and EX; EX and CON were similar. Total relative EI was lower in EX (6284 (SD 2042) kJ) compared with CON (7167 (SD 2218) kJ; $P < 0·05$) and higher in EX + R (7736 (SD 2033) kJ) compared with CON ($P < 0·001$). Appetite and satiety quotients did not differ across conditions ($P \geq 0·10$). Pre-meal explicit liking for fat was lower in EX compared with CON and EX + R ($P = 0·05$). There was time by condition interaction between EX and CON for explicit wanting and liking for fat ($P = 0·01$). Despite similar appetite and EI, adolescents with obesity do not adapt their post-exercise food intake to account for immediate dietary replacement of the exercise-induced energy deficit, favouring a short-term positive energy balance.

Key words: Exercise: Energy replacement: Appetite: Adolescents: Obesity

The prevalence of paediatric overweight and obesity represents a continuing global public health challenge[1] and arises as a consequence of a chronic surplus of energy intake (EI) above energy expenditure[2]. Evidence supports a role for exercise in the control of body weight due to its ability to increase energy expenditure and induce a negative energy deficit in the absence of compensatory changes in EI[3]. The interplay between exercise, EI and appetite control in young people has attracted increasing scientific attention given the direct implications for energy homoeostasis and body weight control.

Abbreviations: CON, rest control; EI, energy intake; EX + R, exercise with energy replacement; EX, exercise with energy deficit; LFPQ, Leeds Food Preference Questionnaire; REI, relative energy intake.

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https://doi.org/10.1017/S0007114519003106 Published online by Cambridge University Press

It is well established that adults respond to acute moderate-to-high-intensity exercise with a transient suppression in appetite and do not exhibit compensatory increases in appetite or *ad libitum* EI on the day of exercise[4,5]. Single bouts of moderate-to-high-intensity exercise have been shown to reduce *ad libitum* EI on the same day in children and adolescents with overweight or obesity, but this effect has not been observed in healthy weight young people[6–8]. A recent review suggests that EI responses to acute exercise in young people may be modulated by physiological, neurocognitive and hedonic pathways[9]. Furthermore, it has been demonstrated recently that the exercise-induced reduction in *ad libitum* EI observed in adolescents with obesity appears to coincide with a reduction in food reward, evidenced by a reduction in the preference for high-fat and sweet foods after exercise[10]. However, research examining hedonic responses to acute exercise stimuli in young people is sparse, and further studies are required to enhance understanding of the interaction between exercise, appetite and EI in this population.

A handful of studies have examined the impact of EI manipulations in the immediate pre- or post-exercise periods on subsequent EI and appetite responses in young people. Specifically, it has been demonstrated that ingestion of a glucose solution immediately after 15 min of rest or moderate-to-vigorous-intensity exercise reduced *ad libitum* EI independent of exercise in boys who were lean or overweight[11]. Similarly, a reduction in *ad libitum* EI has also been observed after a glucose preload was ingested before 40 min of rest or exercise in normal weight boys and men, but the effect was augmented when combined with the exercise bout[12]. A recent study in adolescent boys and girls aged 12–14 years demonstrated that *ad libitum* EI was not altered in response to a mid-morning snack and an isoenergetic bout of cycling completed alone or in combination[13]. However, it is possible that the provision of a highly palatable pizza meal consumed in small peer groups may have influenced their *ad libitum* EI in the snack and exercise conditions[14]. The authors also reported that appetite was suppressed after snack intake but returned to control values before the *ad libitum* meal and were not influenced by exercise[13]. However, it is not known whether replacement of the exercise-induced energy deficit immediately after exercise alters subsequent appetite, EI and food reward responses in adolescents with obesity.

Therefore, the aim of the present study was to compare the effects of acute exercise with and without immediate replacement of the exercise-induced energy deficit on *ad libitum* EI, appetite perceptions and food reward in adolescents with obesity. We formulate the hypothesis that the adolescents will not reduce their *ad libitum* EI in the presence of an energy replacement snack after exercise, favouring then a higher overall energy balance.

Methods

Population

Fourteen adolescents with obesity (according to Cole *et al.*[15]) aged 12–15 years (Tanner stage 3–4) were recruited through the local Pediatric Obesity Centre (Tza Nou, La Bourboule, France) to participate in the present study (six boys, eight girls). The present study was conducted in accordance with the Declaration of Helsinki, approved by the local ethics authorities (Human Ethical Committee: CPP ILE DE FRANCE III; authorisation reference: 2018-A02160-55) and registered with Clinical Trials.gov (trial identifier: NCT03742622). All participants and their parent or legal guardian provided written informed assent or consent, respectively, before the study commenced. Participants were not taking any medications that could interact with the study outcomes, were engaging in less than 2 h of moderate physical activity per week (according to the IPAQ short-form questionnaire)[16] and did not exhibit high cognitive restraint (as assessed using the Child Three-Factor Eating Questionnaire)[17].

Preliminary measures

After a preliminary medical screening visit with a clinical paediatrician to confirm eligibility, preliminary measurements were conducted to assess anthropometry and to determine peak $\dot{V}O_2$. Height and body mass were determined using a standard wall-mounted stadiometer and digital scale (SECA), respectively. BMI was calculated as body mass (kg) divided by height squared (m^2), and BMI percentile was calculated using age- and sex-specific French reference curves[18]. Fat mass and fat-free mass were assessed by dual-energy X-ray absorptiometry (QDR4500A Scanner; Hologic).

Peak $\dot{V}O_2$ test

Participants performed a peak $\dot{V}O_2$ test on a traditional concentric cycle ergometer[19]. The initial power was set at 30 W for 3 min and was increased in 15 W increments every minute until volitional exhaustion. Maximal criteria were: heart rate >90 % of the age-predicted maximum heart rate (210 − 0·65 × age), RER >1·1 and/or $\dot{V}O_2$ plateau. Heart rate was monitored continuously using short-range telemetry (Polar V800; Polar Inc.), and 12-lead electrocardiography monitoring was conducted (Ultima SeriesTM). $\dot{V}O_2$ and CO_2 production were determined using an online breath-by-breath gas analysis system (BreezeSuite Software). Peak $\dot{V}O_2$ was defined as the average of the last 30 s of exercise before exhaustion.

Main trials

Participants completed three 12 h trials (08.00 –20.00 hours) in a random crossover design separated by 1 week: (1) rest control (CON); (2) exercise with energy deficit (EX) and (3) exercise with energy replacement (EX + R). Participants arrived at the laboratory at 08.00 hours on the morning of the trials after a 12 h overnight fast. The adolescents were requested not to engage in any moderate-to-vigorous physical activity during the 2 d that preceded each trial. Similarly, the adolescents were asked to avoid any food overconsumption and to record their intake on the day that preceded their first trial. They were asked to maintain a similar food consumption on the day before their two other trials.

During CON, participants were required to remain quiet and not to engage in any physical activity. During the exercise trials, participants cycled for 30 min (09.45–10.15 hours) at 65 % of their peak $\dot{V}O_2$ and then rested in the laboratory. Heart rate was monitored continuously, and the exercise-induced energy expenditure was estimated using data from the peak $\dot{V}O_2$ test. Immediately after the exercise session in EX – R, participants consumed an individually calibrated snack composed of bread, nuts, fruits and chocolate within 20 min to replace the estimated exercise-induced energy deficit (177 (SD 39) kcal, respecting recommendations for age[20]). (To convert kcal to kJ, multiply by 4·184.)

Standardised and *ad libitum* meals

At 08.00 hours, participants consumed a standardised breakfast respecting the nutritional recommendation for age which consists of white bread, butter, marmalade, yogurt or semi-skimmed milk and fruit or fruit juice which provided 500 kcal. Participants were provided with an *ad libitum* buffet meal for lunch (12.00 hours) and evening meal (07.00 hours). Lunch consisted of beef steak, pasta (Lustucru), mustard (Auchan brand), cheese (Camembert; Auchan brand), yogurt (plain yogurt; Auchan brand), compote (apple compote; Andros), fruits and bread (white bread), and the evening meal consisted of ham or turkey, beans, mashed potato, cheese (Camembert; Auchan brand), yogurt (plain yogurt; Auchan brand), compote (apple compote; Andros), fruit and bread (white bread). Food items were provided in excess of the expected consumption, and participants were instructed to eat until 'comfortably satiated'. The adolescents made their choices and filled their trays individually. Their food selection was weighted by the investigators who served the adolescents. Importantly, the adolescents were not aware that their plates were weighted and did not have any indication regarding the quantity of energy content served. The weighted difference of food items was measured before and after the meal and intakes of energy, and macronutrients were calculated using dietary analysis software (Bilnut v4.0 for Windows). Relative EI (REI) for the *ad libitum* lunch meal and total (*ad libitum* lunch and evening meals combined) was calculated as the EI *minus* the net energy expenditure of exercise.

Subjective appetite ratings

Appetite ratings were assessed throughout the day using visual analogue scales (150 mm scales) at baseline (fasted – 08.00 hours), immediately after breakfast (08.30 hours) and then immediately before (09.45 hours) and after (10.15 hours) exercise, before (12.00 hours) and after (01.00 hours) lunch and before (07.00 hours) and after (08.00 hours) evening meal. Additional measurements were also obtained 30 and 60 min after lunch[21]. Specifically, the questions (i) 'how hungry do you feel?', (ii) 'how full do you feel?', (iii) 'would you like to eat something?' and (iv) 'how much do you think you can eat?' provided an assessment of perceived hunger, fullness, drive to eat and prospective food consumption, respectively. Total daily AUC for each appetite sensation were calculated as well as AUC for the 60 min post-lunch. The satiety quotient for hunger, fullness, prospective food consumption and drive to eat was calculated as follows[22]:

$$\text{Satiety quotient (mm/kcal)} = \frac{\text{pre-lunch appetite (mm)} - \text{mean 60 min post-lunch appetite (mm/h)}}{\text{energy content of lunch (kcal)}} \times 100.$$

Food liking and wanting

The Leeds Food Preference Questionnaire (LFPQ; described in detail by Dalton & Finlayson[23]) provided a measure 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 studies[23] including a recent exercise and appetite trial in young French boys[10]. Explicit liking and explicit wanting were measured by participants using 100 mm visual analogue scales to rate the extent 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 randomised order. 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 with every other type over ninety-six trials (food pairs). Participants were instructed to respond as quickly and accurately as they could to indicate the food they wanted 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). Fat bias scores were calculated as the difference between the high-fat scores and the low-fat scores, with positive values indicating greater liking, wanting or choice for high-fat relative to low-fat foods and negative values indicating greater liking, wanting or choice for low-fat relative to high-fat foods. Sweet bias scores were calculated as the difference between the sweet and savoury scores, with positive values indicating greater liking or wanting for sweet relative to savoury foods and negative values indicating greater liking or wanting for savoury relative to sweet foods.

Statistical analyses

Statistical analyses were performed using Stata software, Version 13 (StataCorp). The sample size estimation was determined according to (i) CONSORT 2010 statement, extension to randomised pilot and feasibility trials[24] and (ii) Cohen's recommendations[25] who has defined effect-size bounds as: small (effect size (ES): 0·2), medium (ES: 0·5) and large (ES: 0·8, 'grossly perceptible and therefore large'). So, with twelve patients by condition, an effect-size approximately 1 can be highlighted for a two-sided type I error at 1·7 % (correction due to multiple comparisons), a statistical power greater than 80 % and an intra-class correlation coefficient at 0·5 to take into account between- and within-

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participant variability. Continuous data are expressed as means and standard deviations or as medians and interquartile ranges according to statistical distribution. The assumption of normality was assessed using the Shapiro–Wilk test. Random-effects models for repeated data were performed with condition and time included as fixed factors and including a random effect for each participant. A Sidak's type I error correction was applied to perform multiple comparisons. As proposed by some statisticians[26,27], a particular focus was also given to the magnitude of differences, in addition to inferential statistical tests expressed using *P* values. The normality of residuals from these models was studied using the Shapiro–Wilk test. Although no sex difference was observed (certainly due to the relatively reduced sample size and then respective number of boys and girls), all statistical analyses were adjusted for sex.

Results

Fourteen 12·8 ± 0·9-year-old adolescents with obesity participated in the present study. Their mean body mass was 95·3 (SD 16·1) kg, with a BMI of 34·8 (SD 5·7) kg/m^2 (*z*-BMI 2·3 (SD 0·4)), percentage of body fat mass of 37·7 (SD 4·2) % and fat-free mass of 57·4 (SD 8·2) kg. The adolescents had a $\dot{V}O_{2peak}$ of 22·25 (SD 4·22) ml/min per kg. Energy expenditure induced by exercise (total duration 30 min) was higher compared with the 30-min resting energy expenditure (177 (SD 39) and 56 (SD 6) kcal, respectively; $P < 0·001$).

Absolute and relative energy intake

Table 1 displays the absolute and REI excluding the energy content of the post-exercise snack in EX – R. Lunch, evening and total daily absolute *ad libitum* EI were not different across the conditions (main effect of condition $P = 0·09$).

Absolute lunch and total EI including the energy content of the post-exercise snack in EX – R were different across conditions (main effect of condition $P = 0·008$ and $P = 0·0013$, respectively) (Fig. 1(A)). Both lunch and total EI were higher in EX – R compared with CON and EX, but no difference was seen between EX and CON (Fig. 1(A)).

Table 1. Absolute and relative *ad libitum* energy intake in the control (CON), exercise with energy deficit (EX) and exercise with energy replacement (EX + R) conditions*
(Mean values and standard deviations)

	CON		EX		EX + R		
	Mean	SD	Mean	SD	Mean	SD	*P*†
Absolute energy intake (kcal‡)							
Lunch	987	315	1003	289	1040	329	0·44
Evening	782	319	676	295	809	177	0·17
Total	1769	532	1678	501	1849	486	0·09
Relative energy intake (kcal‡)							
Lunch	931	315	826	279	1040	329§‖	0·0032
Total	1713	530	1502	488§	1849	486‖	0·0020

* Values are means and standard deviations for *n* 14 and are exclusive of the post-exercise snack consumed in EX – R.
† *P* values represent the main effect of condition.
‡ To convert kcal to kJ, multiply by 4·184.
§ $P < 0·05$ *v.* CON.
‖ $P < 0·001$ *v.* EX.

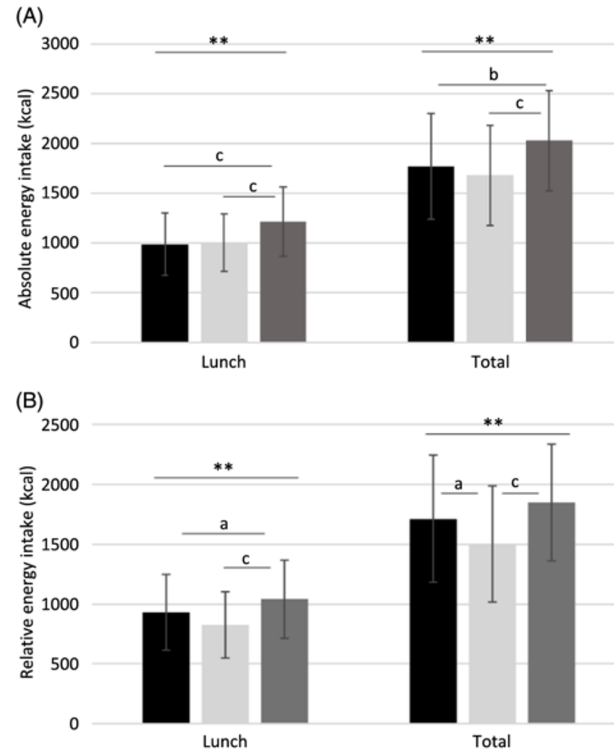

Fig. 1. Absolute (A) and relative (B) energy intake in the control (CON), exercise with energy deficit (EX) and exercise with energy replacement (EX + R) conditions. Values are means and standard deviations for *n* 14. Values for EX – R include the energy content of the post-exercise snack. ** $P < 0·05$ for the main effect of condition; a: $P < 0·05$ *v.* control; b: $P < 0·01$ *v.* control; c: $P < 0·001$ *v.* exercise. ■, CON; ■, EX; ■, EX + R. To convert kcal to kJ, multiply by 4·184.

Lunch REI (including the post-exercise snack in EX – R; main effect of the condition was higher in EX + R (1040 (SD 329) kcal) compared with both CON (931 (SD 315) kcal) and EX (826 (SD 279) kcal) ($P < 0·001$). Lunch REI had a tendency to be lower in EX *v.* CON ($P = 0·08$). Total REI (including the post-exercise snack in EX – R; main effect of the condition was lower in EX (1502 (SD 488) kcal) compared with CON (1713 (SD 530) kcal) ($P < 0·05$) and higher in EX + R (1849 (SD 486) kcal) compared with CON ($P < 0·001$). A tendency was found for total REI to be lower in EX compared with CON ($P = 0·07$).

Fig. 2 illustrates the inter-individual variability of the lunch and total absolute and REI variations between the three experimental conditions.

Macronutrient intake

Absolute protein consumption at the evening meal was different across conditions (main effect of condition $P = 0·02$), with intakes lower in EX (39·6 (SD 16·9) g) compared with CON (58·6 (SD 25·8) g, $P = 0·009$) and EX + R (51·1 (SD 16·8) g, $P = 0·0253$). No differences were observed in absolute protein intake at lunch or overall, or in absolute carbohydrate and fat intake at lunch, evening meal or overall.

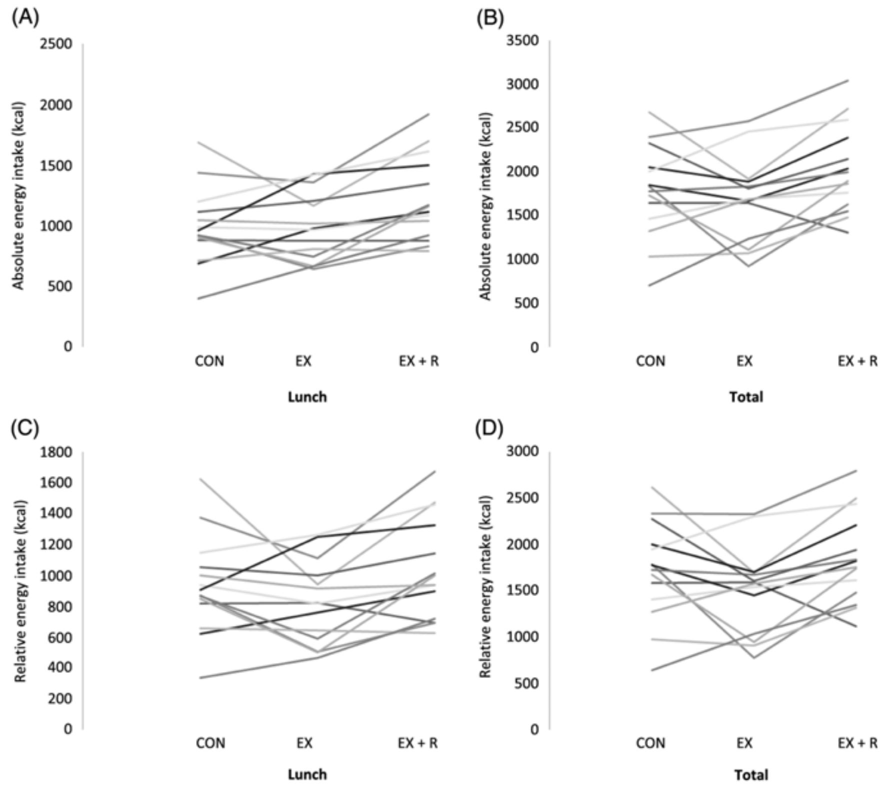

Fig. 2. Individual variation of absolute energy intake at lunch (A) and total (B) and of relative energy intake at lunch (C) and total (D) in the control (CON), exercise with energy deficit (EX) and exercise with energy replacement (EX + R) conditions. Values are means and standard deviations for *n* 14. Values for EX – R include the energy content of the post-exercise snack. To convert kcal to kJ, multiply by 4·184.

The percentage of energy ingested from protein and CHO was not different across conditions at lunch, evening meal or overall. At the evening meal, the percentage of energy ingested through fat was lower in CON (21·9 (SD 10·8) %) compared with both EX (31·3 (SD 9·7) %, $P = 0{\cdot}043$) and EX + R (32·1 (SD 7·8) %, $P = 0{\cdot}023$). In total (lunch and evening meal combined), the percentage of energy ingested from fat was higher in EX + R (30·8 (SD 4·5) %) compared with CON (26·8 (SD 5·6) %, $P = 0{\cdot}0363$) and was marginally higher in EX – R than EX (27·5 (SD 3·8) %) ($P = 0{\cdot}063$).

Appetite ratings

As detailed in Table 2, none of the fasting, pre-lunch or total AUC values for hunger, fullness, prospective food consumption and drive to eat was different across conditions (all main effects of condition $P \geq 0{\cdot}10$). The AUC 60 min post-lunch and satiety quotients, as satiating indicators, did not differ across conditions for any of the appetite ratings (all main effects of condition $P = 0{\cdot}11$).

Food reward

As detailed in Table 3, no condition (exercise *v.* control), time (pre- *v.* post-meal) or interaction (time × condition) effects were found for Choice Taste Bias, Implicit Wanting Taste and Fat Bias and Explicit Liking Taste Bias. Choice Fat Bias did not show any condition or interaction effect. Explicit Wanting Fat Bias was significantly reduced in response to the test meal in CON only ($P = 0{\cdot}001$), and a time × condition interaction was observed between CON and EX ($P = 0{\cdot}017$). Explicit Wanting Taste Bias only showed a significant reduction in response to the *ad libitum* test meal in CON ($P = 0{\cdot}03$). Pre-meal Explicit Liking Fat Bias showed a significant condition effect ($P = 0{\cdot}05$) with EX being significantly lower than both CON ($P = 0{\cdot}016$) and EX + R ($P = 0{\cdot}01$). Explicit Liking Fat Bias also showed a condition × time interaction between CON and EX ($P = 0{\cdot}026$).

Discussion

In accordance with our initial hypothesis, the primary finding of the present study was that 30-min of moderate-intensity cycling did not alter subsequent *ad libitum* EI or appetite in adolescents with obesity, irrespective of whether the exercise-induced energy deficit was replaced immediately after exercise. The absence of adjustments in post-exercise EI suggests that maintenance of the exercise-induced energy deficit may be required to prevent the promotion of a positive energy balance on the same day of exercise.

Absolute EI at the *ad libitum* lunch and evening meals was similar between conditions resulting in higher EI in EX + R when accounting for the energy content of the post-exercise snack. This resulted in a lower REI when the energy deficit was maintained after exercise, but REI was higher in EX + R than CON indicative of a positive energy balance on the day of exercise when the exercise-induced energy deficit was replaced. The lack of modification in post-exercise absolute EI might be explained

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Table 2. Fasting, total AUC and satiety quotients for each appetite rating in the control (CON), exercise with energy deficit (EX) and exercise with energy replacement (EX + R) conditions
(Mean values and standard deviations)

	CON (*n* 14)		EX (*n* 14)		EX + R (*n* 14)		
	Mean	SD	Mean	SD	Mean	SD	*P**
Hunger							
Fasting (mm)	68	48	81	48	97	38	0·10
Pre-lunch (mm)	91	36	83	45	87	37	0·76
SQ (mm/kcal†)	8·7	3·5	7·5	4·3	8·1	5·1	0·59
AUC 60 min post-lunch (mm)	570	681	633	997	665	1061	0·82
Total AUC (mm)	9243	3747	9526	4703	9841	4304	0·51
Fullness							
Fasting (mm)	33	55	21	33	9	9	0·20
Pre-lunch meal (mm)	22	25	27	40	23	30	0·97
SQ (mm/kcal†)	–10·1	4·6	–5·4	9·8	–8·1	5·2	0·26
AUC 60 min post-lunch (mm)	7139	2037	4953	3442	5987	2746	0·11
Total AUC (mm)	23 180	6988	17 837	8877	19 881	7918	0·17
PFC							
Fasting (mm)	71	43	80	44	85	40	0·69
Pre-lunch meal (mm)	97	26	94	42	89	38	0·82
SQ (mm/kcal†)	9·1	3·8	8·6	5·9	7·6	4·3	0·62
AUC 60 min post-lunch (mm)	888	1141	869	1095	905	1267	0·94
Total AUC (mm)	10 253	5005	11 297	5106	10 574	5444	0·84
DTE							
Fasting (mm)	74	48	87	48	96	42	0·30
Pre-lunch meal (mm)	100	36	96	44	89	39	0·63
SQ (mm/kcal†)	9·6	3·9	8·3	3·8	7·8	4·6	0·31
AUC 60 min post-lunch (mm)	659	960	662	777	763	1145	0·79
Total AUC (mm)	10 576	4922	11 106	6076	9701	4826	0·42

SQ, satiety quotient; PFC, prospective food consumption; DTE, desire to eat.
* *P* values represent the main effect of condition.
† To convert kcal to kJ, multiply by 4·184.

by the moderate intensity of the exercise bout. Indeed, while our results are in line with some studies using similar exercise intensities[28,29], other studies conducted in similar populations reported reduced EI after single bouts of vigorous-intensity exercise (>70 % of maximal capacity)[10,30,31]. This anorexigenic effect of vigorous-intensity exercise in adolescents with obesity has been confirmed in a recent systematic review and meta-analysis[8]. It is also possible that the absence of EI modification after exercise with an energy deficit in the present study may reflect the delay between the exercise bout and the *ad libitum* lunch meal. Previous studies have typically provided an *ad libitum* test meal approximately 30 min after exercise cessation[28,31], whereas the *ad libitum* lunch meal was provided 2 h after exercise in the present investigation. In this regard, Albert *et al.* reported lower food intake after moderate-intensity exercise completed 30 min, but not 130 min, before a test meal in healthy weight adolescent boys[32]. Our study was not designed to investigate the importance of EI timing in the post-exercise period; therefore, further research is required before recommendations can be made.

The effect of immediate replacement of the exercise-evoked energy expenditure on subsequent EI responses in young people is restricted to one previous investigation in 12–14-year-old adolescents[13]. In accord with our findings, Varley-Campbell *et al.* did not find any differences in EI after acute exercise regardless of whether the exercise energy expenditure was replaced, resulting in a lower REI when the energy deficit was maintained[13]. Importantly, the authors employed a pizza buffet meal, which may have reduced the sensitivity to detect differences in EI due to the high palatability of the meal[14]. Consequently, the present work adopted a balanced buffet meal that was designed to provide familiar foods without promoting over-, under- or occasional/opportunistic consumption (as previously validated[33]). Furthermore, the buffet meals adopted in the present study allowed the exploration of specific macronutrient intakes. While we did not find any modification in the absolute consumption of fats, proteins and carbohydrates at lunch, absolute protein intake was lower at the evening meal after EX but not after EX + R. Interestingly, the total daily percentage of energy derived from fat was higher in EX + R compared with CON and EX. The reason underpinning these findings is unclear, with previous evidence examining the effect of exercise on macronutrient intake in young people yielded largely conflicting findings[8]. Nevertheless, the findings of the present study contribute to the extant literature examining energy and macronutrient intake responses to acute exercise in adolescents.

It has been shown previously in healthy weight boys and girls that ingestion of a mid-morning snack, both before acute exercise and an equivalent period or rest, suppressed hunger and prospective food consumption and elevated fullness compared with exercise and rest conditions with no snack provision[13]. The present study in adolescents with obesity observed no differences in any of the fasting, pre-meal or total daily appetite sensations after exercise inducing an energy deficit, supporting previous studies in adolescents with obesity[28,34]. Our findings extend the present evidence base by demonstrating that subjective appetite is not altered in adolescents with obesity when the

https://doi.org/10.1017/S0007114519003106 Published online by Cambridge University Press

Table 3. Pre- and post-lunch meal food reward in the control (CON), exercise with energy deficit (EX) and exercise with energy replacement (EX – R) conditions
(Mean values and standard deviations)

	CON (*n* 14)		EX (*n* 14)		EX + R (*n* 14)			Interaction time × condition		
	Mean	SD	Mean	SD	Mean	SD	*P*	CON *v.* EX	CON *v.* EX + R	EX *v.* EX + R
Choice										
Fat bias										
Before meal	6·4	10·4	5·6	10·0	4·8	7·2	0·71	0·97	0·76	0·75
After meal	8·29	10·1	7·6	8·8	6·5	6·3	0·42			
P before *v.* after meal	0·01		0·22		0·26					
Taste bias										
Before meal	5·5	12·3	2·15	13·0	4·4	11·8	0·49	0·21	0·35	0·74
After meal	5·7	12·4	5·54	11·8	7·4	13·2	0·68			
P before *v.* after meal	0·88		0·11		0·06					
Implicit wanting										
Fat bias										
Before meal	4·6	40·3	16·29	25·9	2·6	27·9	0·22	0·06	0·24	0·16
After meal	28·3	47·1	12·51	13·7	24·4	82·9	0·18			
P before *v.* after meal	0·10		0·29		0·12					
Taste bias										
Before meal	18·5	39·8	-0·26	42·0	15·5	30·3	0·78	0·57	0·99	0·32
After meal	20·7	34·6	17·51	29·4	18·7	36·1	0·73			
P before *v.* after meal	0·93		0·18		0·60					
Explicit wanting										
Fat bias										
Before meal	15·5	7·5	11·90	7·5	15·1	14·7	0·80	0·017	0·84	0·26
After meal	4·7	6·1	10·74	9·0	5·7	10·4	0·32			
P before *v.* after meal	0·001		0·92		0·08					
Taste bias										
Before meal	17·2	12·2	16·10	12·0	17·6	20·8	0·87	0·94	0·78	0·84
After meal	9·3	9·4	8·60	10·6	11·8	11·6	0·64			
P before *v.* after meal	0·03		0·12		0·26					
Explicit liking										
Fat bias										
Before meal	14·4	7·4*	1·60	12·9	9·0	16·4*	0·05	0·026	0·50	0·25
After meal	7·9	9·7	8·08	8·2	7·3	8·1	0·97			
P before *v.* after meal	0·09		0·21		0·72					
Taste bias										
Before meal	17·7	12·0	8·90	18·1	15·0	18·5	0·23	0·22	0·17	0·76
After meal	9·2	10·3	7·46	9·4	18·6	15·9	0·15			
P before *v.* after meal	0·06		0·91		0·65					

* $P < 0·01$ *v.* EX.

energy expenditure induced by exercise is replaced, contrasting the previously discussed findings in healthy weight boys and girls[13]. Clearly, the effect of acute exercise on appetite ratings and the interplay between subjective appetite sensations and EI requires further attention in this population, particularly given the largely contradictory results evident in the present literature (for a review, see Thivel & Chaput[35]).

The LFPQ was adopted in the present study to assess the adolescents' food reward immediately before and in response to an *ad libitum* lunch meal. Evidence examining the effect of acute exercise on food reward is relatively sparse[36–38], especially in children and adolescents. Nevertheless, it has been reported recently that the preference for high-fat *v.* low-fat foods was reduced in response to single bouts of aerobic and resistance exercise in healthy adult women using the LFPQ[38]. Furthermore, the hedonic 'liking' of high-fat foods was lower after resistance, but not after aerobic exercise, suggesting a potential role for exercise modality[38]. In adolescents with obesity, Miguet and colleagues showed recently that 16-min of high-intensity interval cycling decreased the relative preference for both fat and sweet taste and implicit wanting for high-fat foods (using the LFPQ) in response to an *ad libitum* meal[10]. The present results also seem to suggest a potential effect of acute exercise on food reward in this population with a reduced pre-meal explicit liking for fat compared with the control condition which was not altered in the presence of post-exercise energy replacement (EX + R). Explicit wanting for fat showed a significant interaction between CON and EX with a lower reduction in response to the test meal on EX compared with CON, whereas no time × condition interaction was observed between CON and EX + R. A significant interaction was also observed between CON and EX for explicit liking for fat that increased in response to the test meal in EX and decreased in CON. This suggests that an exercise-induced energy deficit may influence food reward in adolescents with obesity, while these effects are diminished after immediate replacement of the energy expenditure induced by exercise. Further work is required to confirm these findings and to determine the relevance in relation to exercise, appetite and energy balance in young people.

The present study is limited by the absence of a direct measurement of energy expenditure during the exercise bouts which may have under- or over-estimated the exercise-induced energy deficit. Longer exercise and/or performed at higher intensities might be considered to favour greater energy deficits, which might lead to divergent results. Other limitations like the absence of hormonal indicators (mainly those involved in the control of EI), the lack of control of the level of hydration of the adolescents and the relatively reduced sample size have to be considered when interpreting our results. Nevertheless, the present study is the first to investigate the effect of post-exercise energy replacement on the subsequent appetite and EI responses in adolescents with obesity, a population where weight control strategies are likely to provoke the most clinical relevance.

In conclusion, adolescents with obesity do not alter their post-exercise *ad libitum* EI after immediate dietary replacement of the exercise-induced energy deficit. This results in a short-term positive energy balance which, if sustained over the long term, may have important implications for weight control in this population. Further work is required to confirm the clinical relevance of these findings, but cautious adoption of post-exercise energy replacement practices may be required in adolescents with obesity to optimise the beneficial effects of exercise.

Acknowledgements

The present study was funded by the French University Institute (IUF) and the UGECAM Nutrition Obesity Clinic.

T. D., M. J., D. M., T. A. and Y. B. designed the study. R. J., M. M., F. A. and K. M. performed the data collection. K. B., M. M., G. F., T. D. and P. B. analysed and interpreted the data. T. D., Y. B., D. M., A. T. and M. M. wrote and revised the paper.

The authors declare that there are no conflicts of interest.

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