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# Introducing eccentric cycling during a multidisciplinary weight loss intervention might prevent adolescents with obesity from increasing their food intake: the TEXTOO study

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## Abstract

**Purpose**. The present study compared the appetite responses to an inpatient eccentric *versus* concentric cycling training programs in adolescents with obesity.
**Methods**. 24 adolescents with obesity (12-16yrs; Tanner 3-4) followed a 12-week multidisciplinary intervention (Phase1), after which they were randomized to concentric (CON) or eccentric (ECC) training for 12 weeks (Phase2). Assessment of anthropometrics, body composition (DXA), aerobic power ($VO_{2max}$), energy (EI) and macronutrient intake, food reward, and subjective appetite were performed at baseline, and after Phase1 (T1) and Phase2 (T2).
**Results**. Body mass, BMI, and fat mass (FM%) decreased in both groups ($p<0.001$). FM% reduction was greater in ECC at T2 (-9.9%). EI did not change in either group at T1, but was greater at T2 relative to T1 in CON only ($p<0.001$,+22%). There was no correlation between the change in body mass, FM%, fat-free mass and EI. Hunger ($p=0.002$) and desire to eat ($p=0.001$) were higher in CON vs. ECC with no time effects nor interactions. Prospective food consumption increased in both groups with no group effect nor interaction. Satiety was not different between groups or over time. In ECC, preference for high-fat foods increased ($p=0.03$), and preference ($p=0.004$) and implicit wanting ($p=0.016$) for sweet foods decreased.
**Conclusion**. Eccentric cycling as part of an inpatient multidisciplinary weight-loss intervention might help prevent increased *ad libitum* energy intake compared to concentric exercise training in adolescents with obesity, potentially through distinct effects of the food reward system.

**Key words.** Eccentric cycling, Appetite, Energy intake, Food reward, Pediatric obesity

## Introduction

With one out of five children having obesity in Europe (WHO. **2016**), pediatric obesity is an alarming public health concern. This is particularly concerning since about 83% of adolescents with overweight and obesity will remain so in adulthood (Herman et al. 2009) and will develop associated metabolic disorders that might increase their morbidity and reduce their life expectancy (Lifshitz **2008**). Developing effective weight loss strategies is of high importance. Multidisciplinary interventions combining physical activity, nutritional guidelines and psychological support are recommended among youth with obesity (Boff et al. 2017; Cardel et al. 2019). Such interventions have been shown effective, at least in the short term, leading to significant improvements in body mass and body composition (Zolotarjova et al. 2018), physical fitness (Aguer et al. 2010), cardio-metabolic profile (Caranti et al. 2007), and health-related quality of life (Fonvig et al. 2017), among others factors.

More recent studies have also investigated the potential appetite and eating behavior responses to such weight loss interventions, including subjective appetite sensations, energy intake, macronutrient preferences and food preferences (for review see (Schwartz et al. 2016; Thivel et al. 2019)). Most of the available literature seems to indicate that physical activity-based weight loss interventions favor a reduction in food intake among adolescents with obesity (Schwartz et al. 2016). However, these data are based on self-reported measures, which have been shown to provide under-reported food intake, especially among adolescents with obesity (Burrows et al. 2010). Some studies using objective food intake measurements using *ad libitum* test meals however report increased daily intake in both adults (Myers et al. 2019) and adolescents (Miguet et al. 2019) with obesity. Interestingly, Miguet and colleagues found a significant increase in energy intake after the second phase (5 months) of a 10-month multidisciplinary intervention conducted among adolescents with obesity, compared with the first five months (Miguet et al. 2019). This increase in energy intake could explain the attenuated reduction in body mass and fat mass percentage observed during the second phase of similar interventions (Miguet et al. 2019; Carnier et al. 2013; Julian et al. 2019). Julian and collaborators recently compared the efficacy of eccentric (ECC) *versus* concentric (CON) cycling of similar metabolic loads as part of an inpatient multidisciplinary weight loss program among adolescents with obesity, placing the exercise training in this second phase of the intervention (Julian et al. 2019). According to their results, both exercise interventions favored improved body mass, body composition and aerobic capacity. Interestingly, these improvements were greater in ECC, particularly for fat mass, fat-free mass, lower-limb muscle strength as well as insulin resistance (Julian et al. 2019).

Due to its lower metabolic demand compared with CON exercise when performed at the same mechanical power (Julian et al. 2018), ECC exercise seems particularly suitable for patients with chronic diseases and limited functional and cardiorespiratory fitness. Importantly, the use of eccentric cycling exercise should be prioritized over classical eccentric weight-lifting exercise among patients with obesity, particularly youth. Indeed, cycling exercise, as a non-weight-bearing exercise modality, limits the high solicitation of bone and joints imposed by classical weight-lifting, thus reducing potential pain and injuries. Additionally, eccentric cycling favors the use of a larger muscle mass, larger time under tension and a better control of the imposed mechanical load, optimizing its quantification and the effects of the intervention.

It has also been suggested that ECC exercise could impact mechanisms of appetite control, but this remains to be elucidated (Julian et al. 2018). ECC exercise might indeed have particular effects on the physiological pathways involved in the control of energy intake, mainly through its specific effects on fat-free mass and fat mass (Julian et al. 2018). Fat-free mass and fat mass are both involved in the control of food intake, mainly through their impact on resting metabolic rate as well as insulin and leptin sensitivity (Blundell et al. 2012). Interestingly, ECC exercise has shown to increase brain-derived neurotrophic factor (BDNF) concentrations in both animal models and humans, which is a strong central regulator of energy intake (Hu and Russek 2008; Matthews et al. 2009; Yarrow et al. 2010). In addition to such physiological factors, exercise in general has also been shown to affect energy intake through hedonic pathways (Miguet et al. 2018; McNeil et al. 2015), but this remains to be examined in response to ECC exercise. Although Paschalis and colleagues did not observe any changes in total energy and macronutrient intake in response to an 8-week ECC program compared to CON, their study only included healthy young women (Paschalis et al. 2011). To our knowledge, the appetite and eating behavior responses to chronic ECC exercise among patients with obesity, particularly children and adolescents, remain unexplored. Therefore, the aim of the present work was to compare the effect of an inpatient ECC *versus* CON cycling training program on energy intake, appetite sensations and food reward in adolescents with obesity.

## Methods

### Subjects

Twenty-four adolescents with obesity (12 males and 12 females; Tanner Stages 3-4) were recruited from the Pediatric Obesity Center (Tzanou, la Bourboule, France). To be included, the adolescents had to meet the following criteria: 1) age 12-16 years, 2) having obesity (not overweight) with body mass index [BMI] > 90th percentile, according to the international cut-off points (Cole et al. 2000), 3) being free of any medication that could affect energy metabolism; 4) not being regular tobacco or alcohol consumers, and 5) free of any contraindications to exercise. Detailed information sheets were provided to the adolescents and their legal representatives and written informed consent was obtained. This study received ethical approval (*CPP Est IV*, 2016-A00043-48; ClinicalTrials.gov: NCT02925572).

### Study design

This is a secondary analysis of the TEXTOO study and the entire design has been previously described (Julian, et al. 2019). The main aim of the TEXTOO study was to compare the effect of an inpatient ECC or CON cycling exercise weight loss intervention inducing the same metabolic load, on body composition and muscle strength in adolescents with obesity. Briefly, after a full medical examination to control for their ability to realize the study, the adolescents followed 12 weeks of inpatient classic medical care (Phase 1) (Prado et al. 2009). They were then randomized and assigned, using randomized blocks, to 12 weeks of concentric (CON; 6 girls and 6 boys) or eccentric (ECC; 6 girls and 6 boys) cycling training (Phase 2). Anthropometric and body composition measurements, maximal incremental exercise tests and a full appetite and eating behavior assessment day (daily energy and macronutrient intake, food reward, and appetite sensations) were performed at baseline (T0), after Phase 1 (T1) and after the 12 weeks of CON or ECC training (Phase 2, T2). The study design is illustrated in Figure 1.

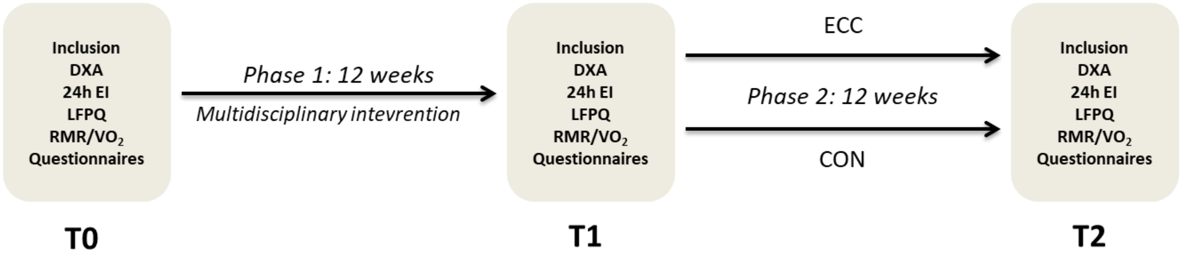

**Figure 1.** Design of the study. **T0, baseline; T1, end of phase 1; T2, end of phase 2; CON, Concentric cycling; ECC, Eccentric cycling; DXA, Dual X-ray absorptiometry; EI. Energy Intake; LFPQ, Leeds Food Preference Questionnaire; RMR, Resting Metabolic Rate.**

## Anthropometric measurements and body composition

Body mass and height were respectively recorded to the nearest 0.1 kg and 0.5 cm using a digital scale and a standard wall-mounted stadiometer (SECA, les Mureaux, France). The adolescents were required to be wearing light clothes and be bare-footed. BMI was calculated as body mass (kg) divided by height squared ($m^2$) and was reported in the age- and sex-dependent international reference curves to get the BMI percentile. 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).

**Maximal oxygen uptake**

An incremental exercise test was performed on a traditional concentric cycling ergometer (Ergoselect 100 P, MSE medical, France) that was different from the one used for the CON cycling training (Optibike Med 600, MSE Medical, France). The initial power was set at 30W during 3 minutes, followed by 15W increments every minute until exhaustion. The experimenters strongly encouraged the adolescents during the test to favor a maximal effort. At least two of the following criteria had to be reached for the test to be defined as maximal: heart rate above 90% of the theoretical maximum heart rate, respiratory exchange ratio (RER = $\dot{V}CO_2/\dot{V}O_2$) >1.1; $\dot{V}O_2$ plateau. The theoretical maximal heart rate was calculated using equations developed in children (208 - 0.7*age) (Tanaka et al. 2001). Cardiac electrical activity was continuously monitored (Ultima Series$^{TM}$, Saint Paul, MN) and combined with breath-by-breath gas exchange measurement (BreezeSuite Software, Saint Paul, MN) to determine $\dot{V}O_2$ and $\dot{V}CO_2$. $\dot{V}O_{2peak}$ was defined as the average of the last 30s of exercise before exhaustion (Rowland 1996). All the adolescents enrolled met these criteria at each time point of the study.

**Resting metabolic rate**

Resting metabolic rate (RMR) was assessed in the morning under fasted state using indirect calorimetry ($K4b^2$, Cosmed, Rome, Italy). The gas analyzer was calibrated in accordance with the manufacturer's recommendations before each evaluation. Participants were asked to stay at rest in a supine position in a thermoneutral room (22–25°C ambient temperature) for 45 min before starting the measurement. After reaching a steady state, $\dot{V}O_2$ and $\dot{V}CO_2$ standardized for barometric pressure, temperature, and humidity were recorded every minute for 20–45 min and averaged over the entire measurement period. Resting metabolic rate (in kcal/day) and RER were then calculated (Weir 1949).

## Eating behavior traits

The Dutch Eating Behavior Questionnaire (DEBQ) was used to assess the adolescents' eating behavior traits (Van Strien et al. 1986). Three domains were studied: restrained eating (individuals' efforts to limit their food consumption to control their body mass or to generate weight loss; 10 items), emotional eating (excessive eating in response to negative moods; 13 items) and external eating (eating in response to food-related stimuli, regardless of the internal state of satiety or hunger; 10 items). Items were answered using six-point Likert scales (never (1), seldom (2), sometimes (3), often (4), very often (5) and not relevant (0)). Their answers were coded according to the recommendations given by Lluch et al. (Lluch et al. 2000). Mean values were calculated for each domain: higher scores indicating greater endorsement of the eating behavior. Scores equal to or above three were used to determine adolescents as restrained, emotional and/or external eaters (Antinori 2004). The French version of this questionnaire has been validated (Lluch et al. 2000).

## Food consumption

Daily food consumption was assessed using *ad libitum* buffet meals at baseline (T0), after Phase 1 (T1) and after Phase 2 (T2). As previously detailed (Miguet, et al. 2019), the participants were offered a calibrated breakfast at 08:00am, prepared according to the recommendations for their age (≈500 kcal) (Murphy and Poos 2002). *Ad libitum* buffet-type meals were served at lunch

(12:00h) and dinner (19:00h). The adolescent's food preferences and eating habits were considered for these buffets. Disliked and preferred items, as well as items liked but not usually consumed were excluded to avoid over-, under- and occasional/opportunistic intake (Thivel et al. 2016). The lunch buffet included: beef steaks, pasta, mustard, yogurt, cheese, fruits as well as apple sauce and bread. For dinner, the adolescents were offered: ham/turkey, mashed potatoes, beans, yogurt, cheese, apple sauce, fruits and bread. Each item was offered in abundance and water was freely available. Participants were instructed to eat until feeling comfortably satiated and extra food was available if needed. Food items were weighed by the investigators before and after consumption, and the macronutrient composition (proportion of carbohydrate, protein and fat) and total EI (kcal) were obtained using the Bilnut 4.0 software. Breakfast, lunch and dinner meals were summed to obtain total daily energy intake. The participants were asked not to engage in moderate to vigorous physical activities between meals and mainly engaged in sedentary activities not involving screens, such as reading, homework, or board games.

## Appetite sensations

Visual analogue scales (VAS; 150-mm) were used to assess subjective appetite sensations (hunger, fullness, desire to eat and prospective food consumption) at regular interval during the day: before and after breakfast, lunch and dinner, and 30 and 60 minutes after breakfast and lunch. 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?" (using French translations of these questions). The participants were asked to rate their answer on a 150-mm scale, from "not at all" to "a lot". This method has been previously validated (Flint et al. 2000).

## Food reward

The Leeds Food Preference Questionnaire (LFPQ) was used to measure food preference and food reward (Dalton and Finlayson 2014). The adolescents completed the LFPQ in a rested fasted state prior to the lunch meal. They were presented with series of pictures of individual food items common in the diet. The pictures were selected from a validated database to be predominantly high (>50% energy) or low (<20% energy) in fat while showing similar familiarity, protein content, palatability and being suitable for the population under study. Explicit liking and wanting were measured by participants rating the extent to which they like each item (“How pleasant would it be to taste this food now?”) and want each item (“How much do you want to eat this food now?”). The pictures were presented individually, in a randomized order and the participants were asked to rate them on a 100-mm VAS. Implicit wanting and relative food preference were assessed using a forced choice task in which the food pictures were paired so that every image from each of the four food types was compared to every other type over 96 trials (food pairs). The adolescents were asked to respond as fast and as precisely as possible to indicate the food they want to eat the most at that time (“Which food do you most want to eat now?”). Reaction times (milliseconds) for all responses were covertly recorded and used to compute mean response times for each food type after adjusting for frequency of selection, in order to evaluate implicit wanting. To measure food choice as a marker of food preference, the mean frequency of selection for each food type was recorded. The responses obtained from the LFPQ were used to calculate mean scores for high-fat, low-fat, sweet or savory 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 preference for high-fat relative to low-fat foods and negative values indicating greater liking, wanting or preference for low-fat relative to high-fat foods. Sweet bias scores were calculated as the difference between the sweet and savory scores, with positive values indicating greater liking, wanting or preference for sweet relative to savory foods and negative values indicating greater liking, wanting or preference for savory relative to sweet foods. The LFPQ has been used widely in adults (Dalton and Finlayson 2014) and youth (Miguet et al. 2018). A French version of this LFPQ has been used, as previously reported (Miguet et al. 2018).

## Exercise training

**Phase 1.** As previously described by Miguet and colleagues (Miguet, et al. 2019), the first 12 weeks of the inpatient multidisciplinary intervention combined physical activity, nutritional education and psychological support. The adolescents were asked to perform four 60-min physical activity sessions per week including aerobic exercise, strength training, aquatic and leisure-time activities (e.g. handball). They also received two hours of physical education per week as part of their classical school curriculum. Nutritional education classes were organized by a dietitian twice per month (one hour each time) and the adolescents received individualized psychological support once per month (one hour). A diet respecting the adolescents' energy requirements, based on age and sex recommendation, was prescribed to the adolescents (Murphy and Poos 2002).

**Phase 2.** Details regarding this second phase of the intervention have been previously published (Julian, et al. 2019). The adolescents were randomly assigned to a 12-week ECC or CON exercise intervention during Phase 2. Both ECC and CON interventions were composed of three ergometer exercise sessions per week, for a total of 36 sessions. The training program started with two weeks of acclimatization where the intensity of the exercise and duration of the sessions were progressively increased in order to protect subjects from delayed onset muscle soreness (DOMS). Importantly, the CON and ECC training sessions were calibrated to induce the same energy expenditure. ECC training was conducted using commercial ECC motor-driven cycling ergometers (Cyclus2 Eccentric Recumbent, RBM elektronik-automation, MSE

Medical, France) and CON training was carried out on CON cycling ergometers (Optibike Med 600, MSE Medical, France). In addition to these specific sessions, the adolescents maintained their two hours of physical education per week as well as a session dedicated to collective games. Participants in both groups received the same dietary counseling throughout the interventional period, although no guidelines for nutritional energy restriction were given in order to investigate the sole impact of the training program. For more details regarding the protocol used in Phase 2, please see Julian and colleagues (Julian et al. 2019).

## Statistical analysis

Stata Software version 13 (StataCorp, College Station, TX, US) was used for statistical analyses. The tests were two-sided, with a type I error set at 5%. Continuous data were expressed as mean ± standard deviation (SD) or median [interquartile range] according to statistical distribution. Normality was checked using the Shapiro-Wilk test. Random-effects models for correlated data were used to assess time effects (T0, T1 and T2) and group effects (CON and ECC), and time by group interaction, considering between and within subject variability (subject as random-effect). The normality of residuals from these models was examined using the Shapiro-Wilk test. Logarithmic transformation were used if needed to achieve the normality of dependent outcomes. Then, multivariable analyses were conducted adjusting for i) age, ii) sex, iii) fat mass or BMI changes between baseline and T1 to compare changes in the ECC and CON groups independently of the preceding modifications in fat mass or body mass. Similar multivariable analyses based on models for repeated measures were conducted to compare appetite sensations (daily hunger, prospective food consumption, satiety and desire to eat) between groups across the time. Moreover, concerning the comparisons of baseline values, quantitative variables were compared between groups using Student t-tests or Mann-Whitney tests when assumptions of t-test were not met. The homoscedasticity was analyzed using the Fisher-Snedecor's test. Categorical parameters were compared between groups using chi-squared or Fisher's exact tests. The relationships between quantitative variables were examined via correlation coefficients (Pearson or Spearman, according to statistical distribution) applying Sidak's type I error correction due to multiple comparisons.

## Results

Of the 24 adolescents who enrolled in the study (12 per group), 10 completed the whole protocol in the ECC group (5 girls and 5 boys) and 11 in the CON group (6 girls and 5 boys). Adolescents left the inpatient program for family and academic reasons, but none dropped out for reasons associated with the program itself. Based on the DEBQ, 26.1% of the whole sample were restrained eaters at baseline against 73.9% unrestrained, 47.8% at T1 (vs. 52.2% unrestrained) and 52.0% at T2 (vs. 48.0% unrestrained).

As detailed in Table 1, body mass significantly decreased in both groups ($p<0.001$) with significant time x group effects at T1 ($p=0.027$) and T2 ($p=0.009$). Although the absolute body mass changes between T1 and T2 (phase 2) were not significantly different between CON (-4.2%) and ECC (-4.5%; $p=0.74$), it was significantly different when adjusted on the T0-T1 body mass changes ($p=0.04$). BMI significantly decreased in both groups during phase 1 and phase 2 ($p<0.001$) with no differences between groups. FM (%) significantly decreased in both groups in phase 1 and phase 2 ($p<0.001$). Although no group effect nor interaction were observed, change in FM (%) during phase 2 was significantly higher in the ECC group (-9.9%) compared with CON (-6.7%) when controlling for the change observed during phase 1 ($p<0.004$). FFM significantly increased between T0 and T1 ($p=0.002$) in the CON group but remained statistically unchanged between T1 and T2, and when considering the whole intervention (between T0 and T2). No changes in FFM were observed in ECC and no group effect was observed.

Table 2 presents the results pertaining to energy and macronutrient intake. Total daily EI significantly increased in both groups during the whole intervention (CON: $p<0.001$; ECC: $p=0.0136$) with no group effect nor interaction. EI did not significantly change in both groups between T0 and T1, but significantly increased during phase 2 in the CON group ($p<0.001$, +22%) but not in the ECC group ($p=0.13$; +8%). Table 2 also details the results regarding the absolute and relative (percentage of total energy ingested) intake of each macronutrient.
There was no correlation between the changes in body mass, FM (%), FFM and EI between T0 and T2, T0 and T1, and T1 and T2. No differences were found between initially restrained and unrestrained eaters in terms of body mass, FM (%) and EI changes between T0 and T1. FFM increased significantly more in the initially restrained adolescents between T0 and T2 (+3.3% vs. -0.25%, $p=0.0032$) and between T0 and T1 (+3.6% vs. +0.84%; $p=0.0075$). Body mass, FM (%), FFM and EI changes during phase 2 were not significantly different between adolescents categorized as restrained or unrestrained at T1.

Figure 2 illustrates the results for appetite sensations. While fasting hunger and satiety were not different between groups at T0, desire to eat and prospective food consumption were significantly higher in the CON group (17 ± 3 and 17 ± 7 mm, respectively) compared with the ECC group (10 ± 5 and 10 ± 5 mm; $p=0.04$ and $p=0.02$, respectively). A group effect was found for overall hunger and desire to eat ($p=0.002$ and $p=0.001$, respectively) with CON having higher appetite ratings than ECC. There were no time effects nor interactions. A significant time effect was found for prospective food consumption in both CON ($p=0.03$; T0 vs. T1 p=0.03; T1 vs. T2 p=0.02) and ECC (p=0.04; T1 vs. T2 p=0.001) with no group effects nor interactions. Satiety was not different between groups or time points.

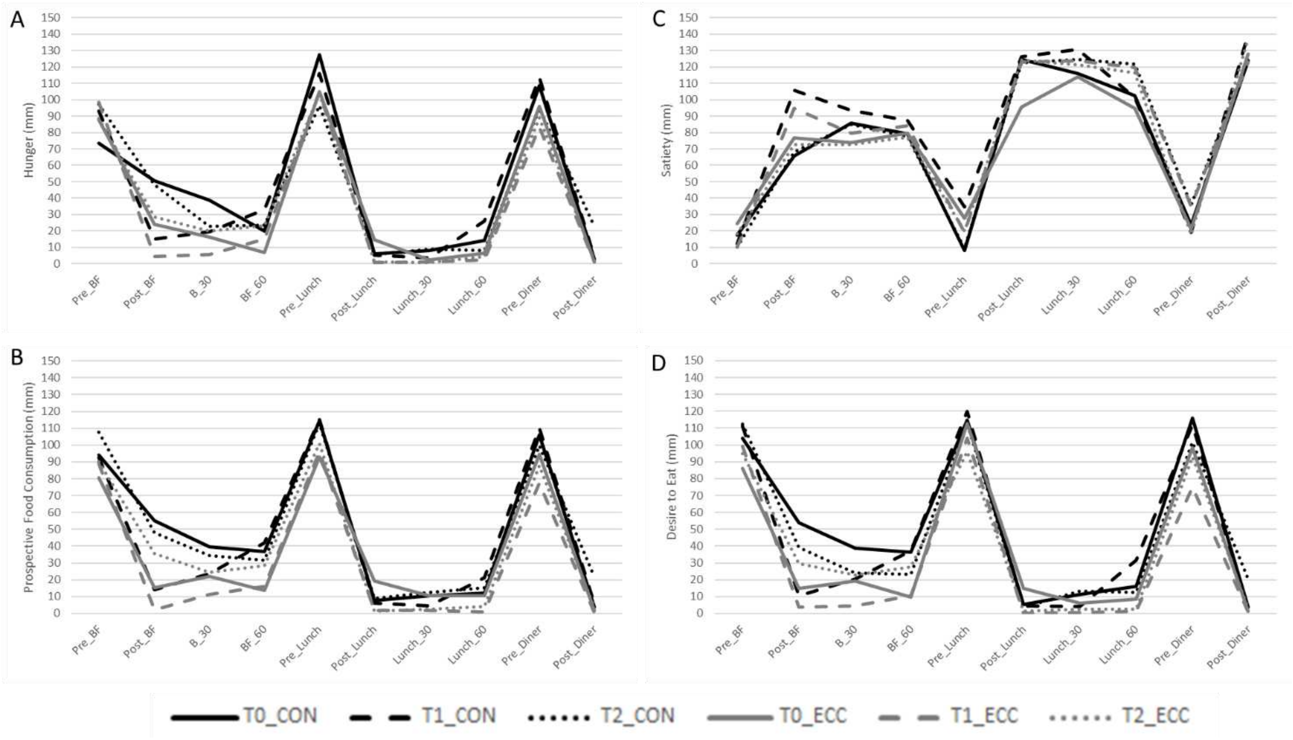

**Figure 2.** Changes in appetite sensations throughout the assessment day during the intervention: Hunger (A); Prospective food consumption (B); Satiety (C); and Desire to eat (D). **Pre-BF, Pre-breakfast; Post-BF, Post-breakfast; B_30, 30 minutes post-breakfast; B_60, 60 minutes post-breakfast; Lunch-30, 30 minutes post-lunch; Lunch-60, 60 minutes post-lunch; T0_CON, Concentric group at baseline; T0_ECC, Eccentric group at baseline; T1_CON, Concentric group at the end of phase 1; T1_ECC, Eccentric group at the end of phase 1; T2_CON, Concentric group at the end of phase 2; T2_ECC, Eccentric group at the end of phase 2**

The LFPQ results can be found in Table 3. Relative fat preference, implicit wanting for fat, explicit wanting for sweet and explicit liking for fat and sweet were not different between groups and did not show any time or interaction effects. While none of the LFPQ dimensions showed a time effect in the CON group, time effects were observed in the ECC group. In ECC, preference for high-fat relative to low-fat foods increased at T2 relative to T0 (p=0.02) and T1 (p=0.02). Preference for sweet relative to savory foods decreased at T1 (p=0.04) and T2 (p=0.001) relative to T0 (i.e. negative values indicate higher preference for savory vs. sweet foods, thus preference for savory foods increased). Implicit wanting for sweet relative to savory foods decreased at T1 (p=0.02) and T2 (p=0.008) relative to T0 (i.e. negative values indicate greater wanting for savory vs. sweet foods). Group effects were observed for the relative preference for fat (p=0.058) and explicit wanting for fat (p=0.009), with CON having greater preference and explicit wanting for high-fat foods than ECC. Group x time interactions were observed at T1 and T2 for the preference for sweet food (p=0.007 and p=0.002, respectively), with CON increasing and ECC decreasing. There was also a group x time interaction for the implicit wanting for sweet food (p=0.002) at T2, with CON increasing and ECC decreasing.

## Discussion

While there is a constant need to improve our weight loss strategies, the present study compared the effect of a 12-week eccentric *versus* concentric cycling intervention on energy intake, appetite, and food reward in adolescents with obesity. According to our results, 12 weeks of eccentric cycling as part of a multidisciplinary intervention might prevent adolescents from the increased energy intake observed in response to similar concentric training matched for metabolic load.

The TEXTOO study is, to our knowledge, the first study to compare such eccentric *versus* concentric cycling interventions of similar metabolic load in adolescents with obesity (Julian et al. 2019). As previously reported, (Julian et al. 2019), significant body mass, BMI and fat mass percentage decreases were observed in both groups during both phase 1 (classical multidisciplinary program) and phase 2 (ECC vs. CON), with a greater body mass reduction in the ECC group. This is of particular importance since body mass and fat mass losses have been shown to be attenuated during the second phase of multidisciplinary interventions that mainly use concentric exercise, in similar populations (Julian et al. 2019; Miguet et al. 2019; Carnier et al. 2013). In their recent study, Miguet and colleagues observed minor body mass and body composition improvements during the second half of a 10-month multidisciplinary weight loss program in adolescents with obesity (Miguet et al. 2019). Interestingly, this was accompanied by a significant increase in EI, particularly in restrained adolescents (Miguet et al. 2019). According to the present results, *ad libitum* daily EI was increased in both groups when considering the entire intervention; however, a significant increase in only the CON group was found during phase 2 (+22% increase from T1) whereas it did not change significantly in the ECC group. Similarly, while protein and fat intake increased in both groups during the intervention (Phase 1 and 2), it did not change significantly in the ECC group during phase 2. ECC training seems to have prevented the adolescents from increasing their food consumption during the second phase of the current weight loss intervention.

Since the control of EI has been shown to be associated with FM and FFM (Blundell et al. 2003; Thivel et al. 2019), it could be suggested that the observed EI differences between ECC and CON are explained by the differential effect of the two interventions on body composition. However, no correlations were found between the changes in body mass, FM (%) and FFM and the EI changes in phase 1 and phase 2, despite slightly higher body mass and FFM at baseline in ECC compared with CON (marginally significant at p=0.09 and p=0.08, respectively), that were not maintained at T1 and T2. While this absence of association between body composition and EI in the present study may be due to the low sample size, other factors related to the hedonic and neurocognitive control of EI could explain our results (Thivel et al. 2019). The role of the level of cognitive restriction has been recently proposed to explain the appetite and EI responses to weight loss in adolescents with obesity (Miguet et al. 2019). Sim et al. have for instance described that physical activity can lead to counterproductive responses in restrained eaters by favoring increased food intake (Sim et al. 2018). More recently, cognitively restrained adolescents with obesity were found to have a greater increase in EI in response to a 10-month weight loss intervention based on concentric exercise, compared with unrestrained eaters (Miguet et al. 2019). Although we did not find EI differences between restrained and unrestrained adolescents when considering our whole sample, 66.6% of the adolescents composing the CON sample were found restrained at T2 against only 27.2% in the ECC sample, which might explain the observed lower energy intake in this latter group. However, this must be interpreted with caution due to the relatively small size of our sample.

In addition to the level of cognitive restriction, food reward has been identified as a key determinant of the control of energy intake (Finlayson and Dalton 2012; Thivel et al. 2019). We found only one study that examined the effect of exercise on food reward in children and adolescents with obesity, suggesting that an acute 16-minute bout of high intensity interval exercise might favor reduced reward for fat and sweet foods compared with a resting condition in 12 to 15 year-old adolescents with obesity (Miguet et al. 2018). In adults with obesity, Martins and collaborators compared the food reward responses to 12 weeks of isocaloric high-intensity interval training *versus* moderate intensity continuous training, not observing any changes over time in both groups (Martins et al. 2017). The present study is to our knowledge the first to investigate the effect of chronic exercise on food reward in adolescents with obesity. Interestingly, our results did not demonstrate a clear effect of exercise per se on the dimensions of food reward. However, CON showed a greater explicit wanting for high-fat foods compared to ECC; and CON experienced an increase in implicit wanting and preference for sweet food during training, while ECC tended towards savoury food during training. These differences in food reward overall and in response to the exercise interventions may explain the greater EI observed in CON during the second phase of the intervention. Preference for high-fat foods may have led to more energy dense food selection during the test meal buffet. The differences in taste preference in ECC and CON are more difficult to interpret as the test foods in the buffet were predominantly savoury, and savoury foods are typically found in the form of entrees, sides and salty snacks that comprise a large proportion of total energy in the diet. An increase in reward for sweet-fat foods has previously been shown to explain overconsumption in women (Dalton and Finlayson 2014), however added salt in savory foods has also been shown to increase energy intake independent of fat content (Bolhuis et al. 2016). Future research should employ test meal designs that include a greater range of sweet and savoury foods varying in fat/energy density.

It is also important to acknowledge that potential underlying group differences that may have contributed to the effects found on EI. Although hunger and desire to eat were significantly higher in CON (group effect), no time effect nor interaction were found, minimizing their potential role in the EI difference observed between groups. This unlikely effect of subjective appetite on the EI difference between CON and ECC is reinforced by the lack of group and time effects in satiety and the increase in prospective food consumption from T0 to T2 in both groups. This confirms once more the potentially uncoupling effect of physical exercise on energy intake and appetite sensations that has been previously described (Thivel and Chaput 2014). Furthermore, we found that savory foods within the LFPQ food stimuli were preferred over sweet foods at all time points during the intervention (negative sweet bias values). Whether this is a characteristic of the sample or due to the food stimuli used within the task is unknown, as well as whether this could have influenced our outcomes. However, it should be noted that the task was performed in the hungry state prior to a meal, when preferences for savory foods are typically greater than sweet foods (Finlayson et al. 2008). Future studies using food images that have been culturally adapted for the French population may shed some light on this observation (Oustric et al. 2019).

The present results must be interpreted in light of some limitations. First, although the TEXTOO study was sufficiently powered for the analyses of the energy intake outcomes, this is a secondary analysis of a larger study which aimed to assess the effect of ECC versus CON training on muscle strength in adolescents with obesity. Similarly, despite our statistical analyses being adjusted for the sex of the adolescents, and Julian et al. previously reporting similar adherence rates and perceived exertion between boys and girls and between groups (ECC *vs.* CON) (Julian et al. 2019), larger studies should be conducted to better examine any differences in the responses to ECC cycling training between boys and girls. Moreover, we used *ad libitum* buffet meals as an objective measure of energy intake instead of self-reported diaries. Although self-reported diaries have been shown to underestimate food intake, particularly in such a population (Burrows et al. 2010), placing the adolescents in a context of food abundance might not represent their normal eating behaviors, especially during a weight loss intervention. Moreover, while the adolescents were used to eating a mid-afternoon snack during their inpatient program, they were not allowed to eat in between meals during our nutritional evaluation days, which might have slightly affected our results. It would have also been of interest to conduct follow-up assessments to analyze the potential long-term responses, but this was not possible for practical reasons.

To conclude, the present study suggests that the appetite and eating behavior responses of adolescents with obesity to an inpatient multidisciplinary weight loss intervention might be different depending on the modality of the exercise used. Introducing eccentric cycling during a multidisciplinary weight loss intervention, previously shown to have a greater effect on body composition over a classical concentric exercise training, might help prevent increased *ad libitum* energy intake observed in response to the concentric intervention in these adolescents; potentially through distinct effects of the food reward system. Further larger longitudinal studies are required to confirm these results and consider the potential inter-individual variability.

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**Table 1.** Anthropometric characteristics and body composition changes during the intervention in CON and ECC

| | T0 | | T1 | | T2 | | Time effect | T0 vs. T1 | T0 vs. T2 | T1 vs. T2 | Group effect | Interaction TxG | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD | | | | | | T1 | T2 |
| ***Body mass (kg)*** | | | | | | | | | | | | | |
| **CON** | 81.3 | 13.3 | 75.5 | 11.6 | 72.3 | 11.8 | <0.0001 | <0.0001 | <0.0001 | 0.0038 | 0.145 | 0.027 | 0.009 |
| **ECC** | 93.9 | 20.3 | 82.8 | 17.4 | 78.8 | 16.0 | <0.0001 | <0.0001 | <0.0001 | 0.0129 | | | |
| *p* | 0.09 | | 0.32 | | 0.22 | | | | | | | | |
| ***BMI (kg/m²)*** | | | | | | | | | | | | | |
| **CON** | 31.8 | 3.8 | 29.4 | 3.6 | 27.6 | 4.0 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | 0.305 | 0.147 | 0.144 |
| **ECC** | 34.8 | 5.5 | 30.8 | 4.9 | 29.0 | 4.5 | <0.0001 | <0.0001 | <0.0001 | 0.0005 | | | |
| *p* | 0.16 | | 0.54 | | 0.53 | | | | | | | | |
| ***Fat mass (%)*** | | | | | | | | | | | | | |
| **CON** | 38.0 | 4.7 | 31.8 | 4.7 | 29.8 | 6.3 | <0.0001 | <0.0001 | <0.0001 | 0.0051 | 0.43 | 0.54 | 0.19 |
| **ECC** | 38.0 | 5.0 | 30.3 | 5.1 | 27.5 | 6.6 | <0.0001 | <0.0001 | <0.0001 | 0.0031 | | | |
| *p* | 0.89 | | 0.35 | | 0.32 | | | | | | | | |
| ***Fat-free mass (kg)*** | | | | | | | | | | | | | |
| **CON** | 48.5 | 9.0 | 49.5 | 8.4 | 48.6 | 8.4 | 0.0088 | 0.002 | 0.086 | 0.14 | 0.085 | 0.23 | 0.40 |
| **ECC** | 55.4 | 9.9 | 55.2 | 10.3 | 54.6 | 10.6 | 0.37 | 0.17 | 0.59 | 0.38 | | | |
| *p* | 0.08 | | 0.12 | | 0.13 | | | | | | | | |

**Data presented as mean ± standard deviation; T0, baseline; T1, end of phase 1; T2, end of phase 2; Interaction TxG, Interaction Time x Group; CON, Concentric group; ECC, Eccentric group; SD, Standard deviation.**

**Table 2.** Changes in energy and macronutrient intake during Phase 1 and Phase 2 in CON and ECC

| | | T0 | | T1 | | T2 | | Time effect | T0 vs. T1 | T0 vs. T2 | T1 vs. T2 | Group effect | Interaction TxG | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | SD | Mean | SD | Mean | SD | | | | | | T1 | T2 |
| ***Energy intake (kcal)*** | | | | | | | | | | | | | | |
| | **CON** | 1856 | 253 | 1936 | 309 | 2396 | 431 | <0.0001 | 0.49 | <0.0001 | 0.0004 | 0.72 | 0.76 | 0.16 |
| | **ECC** | 1932 | 539 | 2080 | 515 | 2232 | 522 | 0.0136 | 0.15 | 0.003 | 0.13 | | | |
| | *p* | 0.8 | | 0.45 | | 0.78 | | | | | | | | |
| ***Protein (g)*** | | | | | | | | | | | | | | |
| | **CON** | 96.8 | 18.2 | 108.0 | 15.8 | 130.9 | 25.5 | <0.0001 | 0.086 | <0.0001 | 0.0006 | | | |
| | **ECC** | 101.3 | 29.4 | 113.5 | 33.3 | 116.8 | 30.4 | 0.0074 | 0.019 | 0.003 | 0.5235 | 0.93 | 0.82 | 0.07 |
| | *p* | 0.88 | | 0.42 | | 0.39 | | | | | | | | |
| ***Fat (g)*** | | | | | | | | | | | | | | |
| | **CON** | 60.4 | 15.4 | 71.4 | 16.3 | 84.8 | 21.4 | 0.0016 | 0.088 | <0.0001 | 0.0463 | | | |
| | **ECC** | 60.2 | 20.5 | 76.0 | 21.9 | 76.9 | 22.0 | 0.0001 | <0.0001 | <0.0001 | 0.8284 | 0.93 | 0.65 | 0.26 |
| | *p* | 0.62 | | 0.57 | | 0.11 | | | | | | | | |
| ***CHO (g)*** | | | | | | | | | | | | | | |
| | **CON** | 236.4 | 34.2 | 215.4 | 38.3 | 274.3 | 60.3 | 0.0017 | 0.189 | 0.034 | 0.0004 | | | |
| | **ECC** | 244.4 | 67.9 | 234.0 | 59.8 | 263.7 | 68.4 | 0.1977 | 0.535 | 0.249 | 0.0761 | 0.63 | 0.65 | 0.55 |
| | *p* | 0.72 | | 0.41 | | 0.58 | | | | | | | | |
| ***Protein (%)*** | | | | | | | | | | | | | | |
| | **CON** | 20.8 | 2.0 | 22.5 | 2.6 | 22.0 | 2.5 | 0.2187 | 0.082 | 0.304 | 0.4913 | | | |
| | **ECC** | 21.0 | 1.7 | 21.7 | 2.9 | 21.0 | 2.7 | 0.5774 | 0.374 | 0.971 | 0.3548 | 0.34 | 0.52 | 0.54 |
| | *p* | 0.98 | | 0.88 | | 0.41 | | | | | | | | |
| ***Fat (%)*** | | | | | | | | | | | | | | |
| | **CON** | 29.2 | 5.4 | 33.1 | 4.7 | 31.8 | 5.1 | 0.0426 | 0.014 | 0.073 | 0.5440 | | | |
| | **ECC** | 28.1 | 3.6 | 32.9 | 4.0 | 31.3 | 5.7 | 0.0003 | <0.0001 | 0.008 | 0.1819 | 0.80 | 0.80 | 0.95 |
| | *p* | 0.83 | | 0.66 | | 0.06 | | | | | | | | |
| ***CHO (%)*** | | | | | | | | | | | | | | |
| | **CON** | 51.0 | 3.9 | 44.8 | 6.1 | 45.8 | 5.6 | <0.0001 | <0.0001 | <0.0001 | 0.6733 | | | |
| | **ECC** | 50.6 | 4.5 | 45.1 | 4.2 | 46.9 | 5.5 | 0.0052 | 0.001 | 0.033 | 0.2940 | 0.80 | 0.60 | 0.34 |
| | *p* | 0.77 | | 0.51 | | 0.06 | | | | | | | | |

**Data presented as mean ± standard deviations; T0, Baseline; T1, end of phase 1; T2, end of phase 2; Interaction TxG, Interaction Time x Group; CON, Concentric group; ECC, Eccentric group; SD, Standard deviation.**

**Table 3.** Changes in relative preference, implicit wanting, explicit wanting and explicit liking for high vs. low fat foods (fat bias) and sweet vs. savory foods (sweet bias) in CON and ECC

| | T0 | | T1 | | T2 | | Time effect | T0 vs. T1 | T0 vs. T2 | T1 vs. T2 | Group effect | Interaction TxG | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD | | | | | | T1 | T2 |
| **Relative preference fat bias (no. of choices)** | | | | | | | | | | | | | |
| ***CON*** | 6.8 | 5.5 | 11.2 | 6.4 | 9.7 | 8.2 | 0.24 | 0.10 | 0.33 | 0.49 | **0.058** | 0.23 | 0.44 |
| ***ECC*** | 3.2 | 9.3 | 3.2 | 7.2 | 7.1 | 6.3 | **0.03** | 0.96 | **0.02** | **0.02** | | | |
| **Relative preference sweet bias (no. of choices)** | | | | | | | | | | | | | |
| ***CON*** | -18.4 | 6.7 | -13.9 | 7.2 | -14.9 | 7.1 | 0.17 | 0.06 | 0.23 | 0.51 | 0.87 | **0.007** | **0.002** |
| ***ECC*** | -10.8 | 10.3 | -15.0 | 8.6 | -17.9 | 6.7 | **0.0049** | 0.04 | 0.001 | 0.2 | | | |
| **Implicit wanting fat bias (a.u.)** | | | | | | | | | | | | | |
| ***CON*** | 19.6 | 15.6 | 23.9 | 19.6 | 13.0 | 32.3 | 0.35 | 0.71 | 0.33 | 0.16 | 0.36 | 0.95 | 0.06 |
| ***ECC*** | 9.1 | 24.7 | 11.5 | 18.1 | 17.0 | 14.4 | 0.15 | 0.65 | 0.06 | 0.15 | | | |
| **Implicit wanting sweet bias (a.u.)** | | | | | | | | | | | | | |
| ***CON*** | -48.9 | 22.3 | -41.9 | 23.0 | -31.8 | 30.7 | 0.18 | 0.5 | 0.07 | 0.22 | 0.92 | 0.07 | **0.002** |
| ***ECC*** | -31.2 | 28.3 | -43.3 | 18.6 | -47.0 | 20.0 | **0.016** | 0.02 | 0.008 | 0.60 | | | |
| **Explicit wanting fat bias (mm)** | | | | | | | | | | | | | |
| ***CON*** | 10.6 | 7.1 | 7.5 | 8.2 | 10.8 | 12.1 | 0.55 | 0.38 | 0.95 | 0.33 | **0.009** | 0.5 | 0.67 |
| ***ECC*** | 3.0 | 14.7 | 3.7 | 10.1 | 0.6 | 4.1 | 0.76 | 0.87 | 0.58 | 0.48 | | | |
| **Explicit wanting sweet bias (mm)** | | | | | | | | | | | | | |
| **CON** | -17.6 | 15.0 | -18.4 | 16.6 | -15.1 | 14.5 | 0.89 | 0.80 | 0.84 | 0.64 | 0.38 | 0.25 | 0.22 |
| ***ECC*** | -19.1 | 22.0 | -10.5 | 20.3 | -7.3 | 11.1 | 0.17 | 0.18 | 0.07 | 0.59 | | | |
| **Explicit liking fat bias (mm)** | | | | | | | | | | | | | |
| **CON** | 11.4 | 9.1 | 9.8 | 13.3 | 8.0 | 12.1 | 0.81 | 0.70 | 0.51 | 0.77 | 0.14 | 0.47 | 0.91 |
| ***ECC*** | 4.4 | 15.3 | 6.9 | 11.0 | 0.8 | 4.6 | 0.33 | 0.52 | 0.39 | 0.13 | | | |
| **Explicit liking sweet bias (mm)** | | | | | | | | | | | | | |
| **CON** | -20.8 | 13.4 | -18.1 | 16.9 | -13.3 | 11.7 | 0.41 | 0.66 | 0.19 | 0.36 | 0.38 | 0.85 | 0.86 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ***ECC*** | -17.3 | 20.6 | -13.4 | 14.1 | -9.2 | 13.6 | 0.36 | 0.50 | 0.15 | 0.43 |

**Data presented as mean ± standard deviation; T0, Baseline; T1, end of phase 1; T2, end of phase 2; Interaction TxG, Interaction Time x Group; CON, Concentric group; ECC, Eccentric group; SD, Standard deviation; a.u., arbitrary unit. Note: Positive values indicate greater liking, wanting or relative preference for high-fat relative to low-fat foods (fat bias) or sweet relative to savory foods (sweet bias).**