Appetite 185 (2023) 106540

Contents lists available at ScienceDirect

Appetite

journal homepage: www.elsevier.com/locate/appet

Effects of aquatic exercise on appetitive responses in adolescents with obesity: An exploratory study

M. Miguet [a,b], B. Pereira [c], K. Beaulieu [d], G. Finlayson [d], P. Matłosz [e], C. Cardenoux [f], Y. Boirie [g,h], M. Duclos [g,h,i], D. Thivel [a], L. Metz [a,*]

[a] Clermont Auvergne University, EA 3533, Laboratory of the Metabolic Adaptations to Exercise under Physiological and Pathological Conditions (AME2P), CRNH Auvergne, Clermont-Ferrand, France

[b] Department of Surgical Sciences, Functional Pharmacology and Neuroscience, Uppsala University, Uppsala, Sweden

[c] Unit of Biostatistics (DRCI), Clermont-Ferrand University Hospital, Clermont-Ferrand, France

[d] Appetite Control & Energy Balance Research Group, School of Psychology, Faculty of Medicine & Health, University of Leeds, Leeds, West Yorkshire, UK

[e] Institute of Physical Culture Sciences, Medical College, University of Rzeszów, 35-959, Rzeszów, Poland

[f] Youth Medical Center, Romagnat, 63540, France

[g] Diet and Musculoskeletal Health Team, CRNH, INRA, University of Clermont Auvergne, Clermont-Ferrand, France

[h] Department of Human Nutrition, Clermont-Ferrand University Hospital, G. Montpied Hospital, Clermont-Ferrand, France

[i] Department of Sport Medicine and Functional Explorations, University Teaching Hospital of Clermont-Ferrand, France

ARTICLE INFO

Handling Editor: Prof. M.M. Hetherington

Keywords:
Pediatric obesity
Exercise
Appetite
Aquatic exercise

ABSTRACT

Aquatic exercise has been suggested as a beneficial modality to improve weight loss, cardiorespiratory fitness and quality of life in adolescents with obesity; however, its impact on appetite control in youth remains unknown. The aim of this preliminary study was to examine the effect of an acute aquatic exercise session on energy intake (EI), appetite feelings and food reward in adolescents with obesity. Twelve adolescents with obesity (12–16 years, Tanner stage 3–5, 9 males) randomly completed two conditions: i) control (CON); ii) aquatic exercise session (AQUA). One hour before lunch, the adolescents stayed at rest outside the water in a quiet room for 45 min on CON while they performed a 45-min aquatic exercise session on AQUA. *Ad libitum* EI and macronutrients were assessed at lunch and dinner, subjective appetite feelings taken at regular intervals, and food reward measured before and after lunch. Paired T-test showed that EI was not different between CON and AQUA at lunch (1333 ± 484 kcal *vs* 1409 ± 593 kcal; $p = 0.162$) and dinner (528 ± 218 kcal *vs* 513 ± 204 kcal; $p = 0.206$). Total daily *ad libitum* EI was significantly higher on AQUA (1922 ± 649 kcal) compared with CON (1861 ± 685 kcal; $p = 0.044$) but accounting for the exercise-induced energy expenditure, relative energy intake did not differ (2263 ± 732 kcal vs 2117 ± 744 kcal, $p = 0.304$). None of the appetite feelings (hunger, fullness, prospective food consumption and desire to eat) and food reward dimensions were significantly different between conditions. These preliminary and exploratory results suggest that an acute aquatic-exercise session might not induce energy compensatory responses in adolescents with obesity.

1. Introduction

The development and implementation of effective weight loss programs should include the prescription of adapted and appropriate physical activity interventions that optimize and maintain the beneficial effects of dietary restrictions. Although acute physical exercise is primarily and mainly considered as a way to increase energy expenditure, some appetitive compensatory responses (including EI, appetite feelings and food reward) have been suggested, which might then have subsequent effects on energy balance (Thivel et al., 2021).

In children and adolescents, most of the available studies examining the effect of exercise on subsequent appetite and energy intake (EI) used cycling or running modalities, mainly demonstrating a transient anorexigenic effect in youth with obesity but not healthy-weight, when performed at higher intensities (Imbeault, Saint-Pierre, Alméras, & Tremblay, 1997; Thivel, Metz, Julien, Morio, & Duché, 2014). However,

* Corresponding author. Clermont Auvergne University, UPR 3533, Laboratory of the Metabolic Adaptations to Exercise under Physiological and Pathological Conditions (AME2P), 3 Rue de la Chebarde, F-63171, Aubière cedex, France.

E-mail address: lore.metz@uca.fr (L. Metz).

https://doi.org/10.1016/j.appet.2023.106540
Received 22 August 2022; Received in revised form 30 November 2022; Accepted 15 March 2023
Available online 17 March 2023

it seems important to question the effect of different exercise modalities on appetite control to better understand the energetic impact of youth's daily physical activities but also to improve the efficacy of our weight management strategies that need to include different types of exercise. While some well-conducted studies have assessed the impact of specific sports and modalities such as netball or rugby on appetite and EI in youth, they mainly concerned normal weight participants (Nemet, Arieli, Meckel, & Eliakim, 2010).

Nemet et al. compared aerobic, resistance and swimming exercises on subsequent EI in 6–10 year-old children with both healthy-weight and overweight (Nemet et al., 2010). Their results indicate a decrease in subsequent food intake after 45 min of resistance type exercise only in healthy weight children, with, in contrast, an increase after the swimming session in kids with overweight (Nemet et al., 2010). Although these last results remain so far the only ones assessing the potential effects of immersed exercise (swimming) on subsequent EI in youth, further studies need to be conducted, not only considering classical swimming but other aquatic exercise modalities that seem more prone to be included into weight loss interventions. Indeed, game- and movement-based aquatic exercise training have been shown to improve weight loss (Irandoust et al., 2021; Lopera et al., 2016), physical fitness (Lopera et al., 2016), quality of life as well as respiratory functions in youth with obesity (Irandoust et al., 2021) while lowering the rate of perceived exertion (Yaghoubi, Fink, Page, Heydari, & Shultz, 2019) and increasing the adolescents' rate of adherence when compared to land-based interventions (Lopera et al., 2016).

Yet uninvestigated in children and youth, some recent studies conducted in adults have compared post-exercise EI and appetite after an acute cycling bout performed either immersed or land based. Ueda et al. (Ueda et al., 2018) for instance asked healthy weight men to cycle for 30 min at 50% of their maximal aerobic capacities once land-based and once immersed (34 °C water), showing lower hunger sensations in response to the water-based trial, without any difference in absolute post-exercise EI (Ueda et al., 2018). Our team recently confirmed this absence of difference between a 30-min moderate intensity land-*versus* aqua-cycling exercise in healthy lean women, pointing however to a lower relative EI after the immersed session due to a higher induced energy expenditure (Metz, Isacco, Fearnbach, et al., 2021). Water temperature also seems to be an important parameter to take into account. Indeed, White et al. had shown that the energy intake after an exercise performed in cold water was higher than in a condition with temperate water (White, Dressendorfer, Holland, McCoy, & Ferguson, 2005). Importantly, proposing a variety of different exercise modalities seems of importance to improve the adhesion of patients when it comes to weight management interventions (O'Malley et al., 2017).

While aquatic-based activities seems appropriate for individuals wishing to begin physical activity due to the non-weight bearing properties of immersion, data are missing regarding their potentially induced appetitive compensatory responses in youth with obesity. In that context, the aim of this preliminary exploratory study was to examine the effects of an acute immersed exercise session on subsequent EI, appetite feelings and food reward, in adolescents with obesity. We hypothesized that aquatic–based exercise would induce a significant increase in energy expenditure, a decrease in appetite after exercise and no food compensation at the subsequent meal.

2. Methods

2.1. Subjects

Fifteen adolescents (aged 12–16 years; Tanner stage 3–5, 9 males) with obesity defined by BMI and according to cut-off point proposed by Cole and al (Cole, Bellizzi, Flegal, & Dietz, 2000) (mean BMI z-score 2.2 ± 0.5; BMI percentile 98.0 ± 2.2), were recruited from the local Pediatric Obesity Center (CMI, Romagnat, France) and participated in this exploratory study. To be included, adolescents had to be free of any medication that could interact with the protocol, be able to engage in physical activities, and had to take part in less than 2 h of physical activity per week (according to the International Physical Activity Questionnaire – IPAQ)(Craig et al., 2003). The adolescents were asked to complete the Dutch Eating Behavior Questionnaire (Brunault et al., 2015), in order to exclude children with high cognitive restraint, as cognitive restriction has been shown to potentially affect post-exercise EI in youth with obesity (Miguet et al., 2019). This work was conducted in accordance with the Helsinki declaration and received an ethical agreement from official authorities (CPP Sud Est VI: AU1178). All adolescents and their legal representative(s) received information sheets and signed consent forms as requested by the national ethical authorities.

2.2. Experimental design

This study was a randomized crossover trial with participants acting as their own controls. After a medical examination conducted by a pediatrician to confirm the eligibility of the adolescents, their body composition was assessed by dual-energy x-ray absorptiometry (DXA), and they performed a maximal aerobic test. The adolescents then randomly completed the two following experimental sessions at least 7 days apart: i) control (CON); ii) aquatic exercise (AQUA). At 8:00 a.m. the adolescents consumed a standardized calibrated breakfast (500 kcal) respecting the recommendations for their age. Lunch and dinner meals were served *ad libitum* used a buffet –type meal. EI was assessed at lunch and dinner, subjective appetite sensations taken at regular intervals throughout the day, and food reward measured immediately before and after lunch.

2.3. Anthropometric and body measurements

Body mass was measured using a digital scale and height was obtained with a standard wall-mounted stadiometer. Body mass index (BMI) was calculated as body mass (kg) divided by height squared (m^2). Body composition (fat mass and fat-free mass) was assessed by a DXA following standardized procedures (QDR4500A scanner, Hologic, Waltham, MA, USA). These measurements were obtained during the preliminary visit by a trained technician.

2.4. Aerobic capacity

After the participants were sitting quietly for 10 min, a measurement of resting metabolic rate was recorded by indirect calorimetry for 15 min. Then, they completed a maximal incremental cycling test supervised by a specialized medical investigator from the Department of Sport Medicine, Functional and Respiratory Rehabilitation (Clermont-Ferrand University Hospital) (Rowland, 1993). The initial power was set at 30 W for the girls and 40 W for the boys for 3 min, following by an increase of 15 W every min. Cardiac electrical activity was monitored (Ultima SeriesTM; Saint Paul, MN, USA), and the test was coupled with heart rate (HR) and respiratory exchanges (VO_2 and VCO_2) were measured throughout the test. Adolescents were encouraged by the experimenters to perform a maximum effort. Criteria to reaching VO_{2peak} were maximal HR (HR_{max}) > 90% of theoretical HR_{max} (210–0.65 × age), respiratory exchange ratio (VCO_2/VO_2) above 1.1 or/and a plateau of VO_2 (Rowland, 1993). VO_{2peak} was defined as the mean of VO_2 during the last 30 s before the exercise was stopped.

2.5. Experimental conditions

Control condition (CON): between 11:00 to 11:45 a.m., the participants remained seated on a comfortable chair (30 min) in a quiet room. They were not allowed to talk, read, watch TV or to complete any intellectual tasks. The energy expenditure of this resting period was then estimated based on the previously performed laboratory-based measurement of the adolescents resting energy expenditure.

Aquatic session (AQUA): between 11:00 to 11:45 a.m., all the participants were able to touch the bottom of the swimming pool and didn't need any floating belt. Swimming pool temperature was 28–29 °C.The participants performed an aquatic-exercise session corresponding to: 10min warm–up (stretching and walking in the swimming pool), 30min aerobic exercise (stationary running, cross-country skiing, jumping jack, jump, leg curl, knee-jogging narrow, side-step, kicks, squat jump, rocking horse), 5min cool-down (stretching). The aquatic session was supervised by a qualified swimming instructor. During the whole session, the adolescents had to wear immersed-specific heart rate monitors (Polar, V800 Kempele, Finland) with a target set around 70% of their peak HR. The exercise-induced energy expenditure (EE) was estimated afterwards based on the results obtained during the maximal oxygen uptake evaluation.

2.6. Energy intake

During the two experimental sessions, adolescents received their breakfast at 8:00 a.m. Lunch and dinner meals were served *ad libitum* using buffet-type meals at 12:00 and 18:30, respectively. The content of the buffet was determined using a food preference and habits questionnaire completed by participants during the inclusion visit. Top rated items and liked items but not usually consumed were excluded to limit overconsumption and occasional eating. Meals were prepared in the experimental kitchen and eaten in a dedicated dining room. The experimenters weighed the food items before and after the meal. This methodology was previously validated and used in previous studies (Thivel, Genin, Mathieu, Pereira, & Metz, 2016). Importantly, the adolescents were not informed about the main purpose of the study and that their EI was weighed. The ANSES nutritional composition table was used to calculate the EI and macronutrient ingestion (quantity and proportion) ("Ciqual Table", ANSES 2020). Total relative energy intake (REI) and REI at lunch were calculated according to the following formula as previously used in several studies (Masurier et al., 2018; Miguet et al., 2018) REI (kcal) = EI (kcal) – EE of the condition (kcal), using the exercise-induced EE for AQUA and based on the adolescents resting metabolic rate for CON (for the same duration as exercise for each adolescent).

2.7. Subjective appetite sensations

Appetite sensations were measured with non-graduated visual analogue scales (VAS) of 150 mm (Drapeau et al., 2005). Participants reported their hunger, fullness, desire to eat (DTE), and prospective food consumption (PFC) before and after each meal during the day, before and after the exercise bout (AQUA) or corresponding rest period in CON, and 30 min and 60 min after lunch.

2.8. Food preferences and food reward

Participants completed the Leeds Food Preference Questionnaire 30 min before and after lunch. This questionnaire was developed and validated to measure the different components of food reward, liking and wanting (Finlayson, King, and Blundell 2007). Subjects were asked to answer questions about images of food divided in four categories: i) savoury and high-fat food; ii) savoury and low-fat food; iii) sweet and high-fat food and; iv) sweet and low-fat food. The measurement of explicit liking and wanting was performed using a VAS (100 mm) to answer the following questions: i) "How pleasant would it be to taste this food now?" (explicit liking) and; ii) "How much do you want to eat this food now?" (explicit wanting). Then, a "forced choice" between two food images allowed to measure food preferences (food choice). Frequency and speed of image selection were registered and enabled to measure implicit wanting. We obtained 2 scores, the "fat bias" and the "sweet bias", for each food reward component. The fat bias score was calculated by subtracting low-fat scores from high-fat scores, and the sweet bias score was obtained by subtracting savoury scores from sweet scores. If the score is above 0 for the fat bias or the sweet bias, there is a greater preference for high-fat food and sweet food, respectively (Oustric et al., 2021).

2.9. Statistical analysis

The sample size estimation was calculated according (i) to differences reported in the literature (White et al., 2005) and (ii) to effect-size bounds recommended by Cohen's (Cohen, 1988): small (ES: 0.2), medium (ES: 0.5) and large (ES: 0.8, '"grossly perceptible and therefore large"). Power calculation based on previous work (White et al., 2005) suggested that a sample size of 11 participants would allow detection of at least 40% difference in energy intake between exercise conditions with a standard deviation of 40%, a probability of 0.05, and a beta level of 0.80. Continuous data were expressed as mean ± standard deviation (SD). Area under the curve (AUC) for subjective appetite sensations for lunch (Lunch+60min AUC) and the day (Total AUC) were calculated using the trapezoidal method. The assumption of normality was assessed using the Shapiro-Wilk test. The comparisons between conditions (CON and AQUA) were carried out using random-effects models for cross-over designs considering the following effects: i) condition, period, sequence, and their interaction as fixed effects and; ii) participant as random-effect to model between and within subject variability. The normality of residuals estimated from these models was analyzed as aforementioned. When appropriate, a logarithmic transformation was applied to access the normality of dependent variables. Spearman correlations were performed between continuous variables (EI, delta EI [CON EI – AQUA EI], FM%, FFM kg, body mass and BMI). The statistical analyses were performed using Stata software version 15 (StataCorp, College Station, US). Statistical tests were two-sided with the type I error set at 5%.

3. Results

Of the 15 initially enrolled adolescents, complete data were obtained for 12 of them. Mean body mass was 98.3 ± 11.6 kg, BMI was 35.9 ± 3.3 kg m^2. Fat-free mass was 60.3 ± 16.5 kg and fat mass was 36.4 ± 4.6%. The adolescents had a mean $VO_{2\ peak}$ of 2.2 ± 0.4 L min^{-1} and performed the 45-min aquatic exercise at 68 ± 8% of their maximal hear rate. The resting energy expenditure in CON was 74 ± 11 kcal. The absolute energy expended during this exercise session was estimated at 298 ± 53 kcal and the net energy expenditure (Absolute EE-Resting EE) were 224 ± 35 kcal.

3.1. Energy intake and relative energy intake

Full detailed results regarding EI and REI are presented in Table 1. Food intake at the *ad libitum* lunch test meal was not different between CON (1333 ± 484 kcal) and AQUA (1409 ± 593 kcal; p = 0.162) (ES: 0.14). Similarly, EI at the *ad libitum* dinner test meal was not different between conditions (CON: 528 ± 218 kcal and AQUA: 513 ± 204 kcal;

Table 1
Energy intake and relative energy intake, in response to aquatic exercise session (AQUA) or rest (CON) in adolescents with obesity.

	CON	AQUA	*p* value	Cohen's d
	Mean (±SD)	Mean (±SD)		Effect size
Lunch EI (kcal)	1333 (±484)	1409 (±593)	0.162	0,14
Lunch REI (kcal)	1249 (±524)	1147 (±679)	0.061	0,17
Dinner EI (kcal)	528 (±218)	513 (±204)	0.206	0,07
Total EI (kcal)	1861 (±685)	1922 (±649)	**0.044**	0,09
Total REI (kcal)	1763 (±732)	1617 (±744)	0.310	0,20

CON: control session; AQUA: Aquatic exercise session; EI: energy intake; REI: relative energy intake (EI-EE); SD: Standard Deviation.

p = 0.206, ES:0.07). Total daily *ad libitum* EI was however significantly higher on AQUA (1922 ± 649 kcal) compared with CON (1861 ± 685 kcal; p = 0.044) (ES:0.09). No significant difference was found for both lunch and total daily REI between conditions (p = 0.206 and p = 0.310 respectively). There was no significant correlation between the delta EI [CON EI lunch – AQUA EI lunch] and body mass (p = 0.813; r^2 = −0.089), BMI (p = 0.417; r^2 = 0.298), FM% (p = 0.359; r^2 = 0.333) and FFM (kg) (p = 0.547; r^2 = −0.223). Similarly, there was no significant correlation between the delta EI [CON total daily EI – AQUA total daily EI] and body mass (p = 0.914; r^2 = 0.041), BMI (p = 0.651; r^2 = 0.169), FM% (p = 0.904; r^2 = 0.045) and FFM (kg) (p = 0.961; r^2 = −0.018).

3.2. Macronutrient intake

Regarding protein intake, both in absolute and in percentage of the total ingested energy, there was no difference between conditions at lunch and dinner. Only the total daily intake of protein in absolute was found significantly lower on AQUA (108 ± 44 g) compared with CON (125 ± 49 g; p = 0.020) (ES:0.37). While lunch and total daily absolute and relative fat intakes did not differ between conditions, it was lower at dinner on the AQUA day in both absolute (CON: 9 ± 6 g, AQUA: 5 ± 2 g; p = 0.018, ES:0.15) and relative (CON: 14.3 ± 6.5%, AQUA: 9.8 ± 1.6%; p = 0.007; ES:0.42). The absolute intakes of CHO at lunch and total daily were found significantly lower on CON compared to AQUA (p = 0.0001; ES:0.23 and p = 0.001; ES:0.33 respectively). The relative intake of CHO at dinner was significantly lower on CON compared with AQUA (p = 0.0001; ES:1.02) with a tendency for the total daily relative intake (p = 0.053; ES:0.70). Full results are detailed in Table 2.

3.3. Subjective appetite feelings and food reward

As detailed in Table 3, except fasting hunger and PFC that were found significantly higher on AQUA (129 ± 28 mm and 126 ± 26 mm, respectively) compared with CON (99 ± 35 mm and 78 ± 56 mm, respectively) (p = 0.003, ES:0.90 and p = 0.015; ES:1.09) respectively), no significant differences were observed between conditions.

Regarding food reward, none of its sub-components was found significantly different between conditions as displayed in Table 4.

4. Discussion

To our knowledge, the present work investigated for the first time the effects of an acute aquatic-based exercise session on EI, appetite feelings and food reward in adolescents with obesity. According to our results, *ad libitum* REI at both lunch and dinner (and total daily REI) were not impacted by the 45-min aquatic exercise session. However, daily EI during the aquatic session was significantly higher than during the control session. When considering the EI at the meal that directly followed the aquatic exercise, our results discord with previously published ones (Nemet et al., 2010; Thackray et al., 2020). Indeed, Nemet et al. (2010) showed an increase in subsequent food intake after a 45-min

Table 3
Appetite sensations during rest condition (CON) and exercise condition (AQUA).

	CON Mean (±SD)	AQUA Mean (±SD)	*p VALUES*	*Cohen's d* Effect size
Hunger				
Fasting	99(±35)	129(±28)	**0.003**	0.94
Pre-exercise/rest	24(±30)	34(±35)	0.178	0.30
Post-exercise/rest	110(±48)	119(±35)	0.360	0.21
Pre-lunch	143(±12)	147(±7)	0.086	0.40
AUC 60min post lunch	55(±15)	251(±597)	0.312	0.46
Pre-dinner	125(±32)	113(±48)	0.465	0.29
Daily AUC	29173 (±5710)	31561 (±12473)	0.631	0.24
Fullness				
Fasting	13(±21)	9(±1)	0.063	0.26
Pre-exercise/rest	72(±60)	76(±51)	0.835	0.07
Post-exercise/rest	18(±37)	11(±21)	0.506	0.23
Pre-lunch	1(±0)	2(±4)	0.317	0.35
AUC 60min post lunch	8420(±869)	8405(±963)	0.939	0.01
Pre-dinner	19(±37)	12(±22)	0.385	0.22
Daily AUC	51387 (±16581)	52137 (±11492)	0.823	0.05
Desire To Eat				
Fasting	104(±39)	129(±25)	0.105	0.76
Pre-exercise/rest	56(±51)	36(±45)	0.345	0.41
Post-exercise/rest	112(±41)	128(±27)	0.087	0.46
Pre-lunch	140(±21)	144(±9)	0.349	0.24
AUC 60min post lunch	53(±13)	58(±15)	0.303	0.35
Pre-dinner	128(±32)	117(±38)	0.452	0.31
Daily AUC	31586 (±6478)	32448 (±12989)	0.911	0.08
Prospective Food Consumption				
Fasting	78(±56)	126(±26)	**0.015**	1.09
Pre-exercise/rest	43(±42)	45(±48)	0.873	0.04
Post-exercise/rest	105(±40)	118(±32)	0.481	0.35
Pre-lunch	135(±37)	139(±12)	0.735	0.14
AUC 60min post lunch	116(±145)	285(±697)	0.517	0.33
Pre-dinner	122(±32)	118(±31)	0.624	0.12
Daily AUC	30014 (±7337)	32475 (±11144)	0.663	0.26

CON: control session; AQUA: Aquatic exercise session; SD: Standard Deviation; data are expressed in mm and mm/min for AUC; AUC: Area Under the Curve.

Table 2
Absolute (grams) and relative (percentages) macronutrient consumption at each meal during aquatic exercise session (AQUA) or rest (CON).

	CON		AQUA		*p* value		Cohen's d Effect size	
	Grams Mean (±SD)	% Mean (±SD)	Grams Mean (±SD)	% Mean (±SD)	Grams	%	Grams	%
Lunch protein	75 (±24)	22.8 (±2.4)	76 (±36)	21.9 (±3.6)	0.697	0.111	0.03	0.29
Dinner protein	50 (±32)	40.0 (±29.0)	31 (±17)	23.4 (±6.5)	0.782	0.948	0.74	0.79
Total protein	125 (±49)	27.4 (±7.4)	108 (±44)	22.6 (±3.0)	**0.020**	0.994	0.37	0.85
Lunch fat	50 (±18)	33.9 (±5.0)	50 (±21)	33.1 (±6.8)	0.678	0.719	0	0.13
Dinner fat	9 (±6)	14.3 (±6.5)	5 (±2)	9.8 (±1.6)	**0.018**	**0.007**	0.89	0.95
Total fat	59 (±20)	28.6 (±2.7)	56 (±21)	26.7 (±5.7)	0.821	0.387	0.15	0.42
Lunch CHO	142 (±62)	42.3 (±6.0)	158 (±76)	43.9 (±9.8)	**0.000**	0.464	0.23	0.19
Dinner CHO	73 (±22)	57.7 (±10.9)	85 (±30)	67.8 (±8.7)	0.159	**0.000**	0.46	1.02
Total CHO	215 (±82)	46.2 (±3.9)	243 (±87)	50.3 (±7.2)	**0.001**	**0.053**	0.33	0.70

CON: control session; AQUA: Aquatic exercise session; CHO: Carbohydrate; SD: Standard Deviation.

Table 4
Relative preference, implicit wanting, explicit wanting and explicit liking for high vs low fat foods and sweet vs savory foods, between rest (CON) and exercise condition (AQUA).

		CON			AQUA			p PRE	Cohen's d Effect size PRE	p POST	Cohen's d	p DELTA	Cohen's d
		PRE	POST	DELTA	PRE	POST	DELTA				*Effect size POST*		*Effect size DELTA*
Relative preference	**Fat bias**	6.6(±9.1)	4.6(±9.1)	−1.0(±6.2)	6.1 (±9.9)	3.6(±8.9)	−1.2(±6.8)	0.189	0.05	0.511	0.11	0.611	0.03
	Taste bias	2.5(±11.2)	6.9(±9.4)	5.2(±6.5)	−0.8 (±11.1)	6.6(±8.3)	7.7(±9.1)	0.795	0.29	0.651	0.03	0.252	0.31
Implicit wanting	**Fat bias**	16.7 (±31.2)	−13.1 (±108.3)	−31.9 (±90.9)	15.3(±26.1)	3.1(±24.5)	−6.8(±23.5)	0.574	0.04	0.439	0.20	0.313	0.37
	Taste bias	0.6(±36.0)	13.8(±41.9)	16.3(±37.4)	6.4(±45.4)	55.1 (±87.4)	47.5 (±113.0)	0.300	0.14	0.085	0.60	0.380	0.37
Explicit wanting	**Fat biais**	2.8(±19.7)	1.4(±8.4)	−1.2(±20.4)	7.8(±11.3)	4.6(±10.7)	−3.0(±12.5)	0.326	0.31	0.105	0.33	0.936	0.10
	Taste bias	4.4(±20.5)	4.7(±13.5)	0.9(±16.8)	4.8(±12.2)	5.7(±14.9)	1.1(±7.1)	0.310	0.02	0.422	0.07	0.799	0.01
Explicit liking	**Fat biais**	6.0(±15.3)	0.9(±9.6)	−5.1(±18.3)	9.4(±16.7)	5.3(±10.3)	−3.7(±17.3)	0.189	0.21	0.177	0.44	0.849	0.07
	Taste bias	1.4(±16.4)	3.3(±14.6)	2.3(±12.3)	6.1(±17.7)	7.2(±17.2)	1.2(±16.0)	0.068	0.27	0.462	0.24	0.448	0.07

CON: control session; AQUA: Aquatic exercise session; PRE: pre-lunch; POST: Post-lunch; SD: Standard Deviation.

swimming session in 6–10 year-old overweight youth (Nemet et al., 2010).

More recently, Thackray et al. also showed contradictive results, highlighting a greater food intake after an hour of swimming in healthy adults (Thackray et al., 2020). However, our results align with the absence of an immediate increased intake observed by King and colleagues in healthy lean adults despite higher subsequent appetite feelings (after 60 min of swimming) (King, Wasse, & Stensel, 2011). While these last studies used classical swimming exercise, the session performed in the present work relied on water fitness exercises, which might have different appetitive implications as observed when using land-based exercises whose modalities (e.i. cycling *vs.* running) have been shown to induce different subsequent appetitive responses (for review see Schubert, Desbrow, Sabapathy, & Leveritt, 2013). Therefore, our results seem close to those we have previously reported, where we did not detect any subsequent EI differences between rest and land-based fitness and aqua-cycling sessions (Metz, Isacco, Fearnbach, et al., 2021).

Interestingly, while land-based moderate-to-high intensity exercise performed an hour before a meal has been shown to reduce subsequent food intake in adolescents with obesity, our results seem to indicate that this effect might not exist while exercising immersed. Indeed, although the 45-min aquatic session was performed at moderate-to-high intensity (mean heart rate 68 ± 8% of maximal heart rate), the adolescents' EI was not modified. These results might suggest the potential role played by the mechanical load of body mass on post-exercise appetitive responses when exercising on land (especially during weight-bearing activities such as running and resistance training), which is reduced when immersed due to water density and Archimedes' Law stating that liquid exerts a buoyant force that allow an immersed body to float. This indeed recalls the results from Miguet et al. (2018) who showed a negative association between BMI, body mass, fat-free mass and fat mass and post land-based exercise EI in adolescents with obesity, already suggesting the potential importance of the mechanical load on appetitive responses to exercise in this population. This is reinforced here by the absence of correlation between these anthropometric and body composition variables and the adolescents' post-exercise intake. The relationship between mechanical load, body mass and food intake has been explored in preclinical studies (Bake et al., 2021; Jansson et al., 2018) and seems to suggest that artificially increasing loading results in reducing food intake, and conversely. Results from non-weight bearing activity such as swimming (Nemet et al., 2010; Thackray et al., 2020), which increase subsequent energy intake, as well as the increase in total energy intake observed here in response to a water aerobics session, are consistent with the concept of an inverse relationship between mechanical load and post-exercise food intake. This relationship between mechanical load and food intake remains poorly understood in humans and the aquatic environment could allow a more accurate assessment of the effect of a decrease in mechanical load. However, beyond the decrease in apparent weight resulting from buoyancy, other properties of water could impact these appetitive responses.

Importantly, other characteristics that are specific to immersed exercise, such as temperature, might have influenced our results. Indeed, while in adults cold temperatures (below 20 °C) have been shown to increase subsequent food intake (Crabtree & Blannin, 2015; Shorten, Wallman, & Guelfi, 2009; White et al., 2005) we have recently shown that there was no difference in EI between cold (18–20 °C) and tempered (28 °C) water during a cycling session (Metz, Isacco, Beaulieu, et al., 2021). Since our aquatic session was performed in a therapeutic pool, the temperature was set between 28 and 31 °C, which might then contribute to explain our results.

As previously showed after both land-based exercise in adolescents with obesity (Nemet et al., 2010) and immersed exercise in healthy adults (Thackray et al., 2020), the REI at lunch appeared to be lower in AQUA compared to CON by ~100 kcal, showing the beneficial effect of the exercise-induced energy expenditure on overall energy balance.

However, while total daily EI was slightly higher in AQUA compared with CON, this beneficial effect on REI disappeared throughout the overall day despite a 150-kcal difference between the two conditions. This absence of significant reduction of the mean total daily REI on the exercise day can be explained by the modest sample size and the large heterogeneity usually observed in such studies, as illustrated by a variation of EI between the two conditions at lunch and total ranging from −622 kcal to +469 kcal and from −555kcal to +363 kcal, respectively. It is however important to highlight that the lunch, dinner and total EI of the adolescents on CON are highly correlated with their intake on AQUA, suggesting that the aquatic session had a quite homogenous and coherent effect (not adding an inter-individual variability to the between-conditions energy intake modifications). Although the results related to macronutrient intake remain difficult to interpret due to our modest sample size and to the relatively small (despite significant) observed changes, it can be noticed that the higher total EI on AQUA seems to be attributable to a clear significant increase in carbohydrate. Further studies are still needed to better understand the effect of acute exercise on subsequent macronutrient intake responses, the available literature showing a high heterogeneity of results so far.

Regarding appetite feelings, hunger, fullness, prospective food consumption or desire to eat were not different between the resting and the aquatic-exercise session. These results are in line with the actual literature examining the effect of acute exercise on appetite sensations in adolescents with obesity (Fillon et al., 2020; Miguet et al., 2018; Pélissier et al., 2022) as well as with the limited data regarding immersed exercise in adults (Metz, Isacco, Miguet, et al., 2021; Thackray et al., 2020). Indeed, studies using aqua cycling (Metz, Isacco, Beaulieu, et al., 2021; Metz, Isacco, Fearnbach, et al., 2021; Metz, Isacco, Miguet, et al., 2021) or classical swimming (Thackray et al., 2020) also did not observe any impact on appetite feelings in healthy adults. Similarly, in line with Thackray et al. (2020) who report the only food reward-related results in response to a swimming session, none of the food reward dimensions were modified in response to the aquatic-session. Since studies remain few and contradictory regarding the effect of acute exercise on food reward in adolescents with obesity, further research is needed.

The results of this exploratory work have to be interpreted in light of some limitations. Although the relatively modest sample size composes the main limitation, it remains in the range of previously published studies assessing the effect of exercise on appetite control in youth with obesity (Masurier et al., 2018; Miguet et al., 2018; Thivel et al., 2014). Secondly, although the use of specific water-based heart rate monitors is a strength of this work, the evaluation of energy expenditure rests on an indirect estimation, which might limit our results. In line with previous study (Metz, Isacco, Fearnbach, et al., 2021), we decided no immersion as a control condition because being rested immersed in water lacks of coherent meaning in the practical application. The lack of evaluation of the adolescents' perceived exertion would have been of particular interest since some authors have shown an impact of this rate of perceived exertion of post-exercise energy intake in youth (Fearnbach et al., 2017). The potential role of perceived exertion on the appetitive response after aquatic exercise in patients with obesity should be considered in future studies although a recent review suggests that there is no difference between land and aquatic environments for this parameter for healthy people (Andrade et al., 2022). The short-term evaluation of the adolescents' appetitive responses could also be considered as a limitation since some evidence points towards potential longer effects, possibly up to 72 h after the exercise (Rocha, Paxman, Dalton, Winter, & Broom, 2015). Moreover, lunch and dinner were served *ad libitum* using buffet-type meals which facilitate excessive energy intake. In the present study, we observed that participants ingested considerably more food at lunch and had self-regulation at dinner. Very few studies are available in the literation to discuss this question and further investigations are needed. Finally, the present exploration relies on an acute bout of immersed exercise and longer studies should be conducted to examine the potential appetitive adaptations to a repeated exposure.

In conclusion, the present exploratory study suggests that an acute aquatic-exercise session does not induce compensatory appetitive responses in adolescents with obesity, which might be due to some specific adaptations related to immersion. These results suggest that water aerobic exercise has a place as part of weight loss physical activity interventions whenever possible. Indeed, beyond the health benefits of physical activity, it seems essential to vary the modalities proposed to encourage the adherence of the patients with obesity in a regular practice. This might of particular importance when it comes to kids suffering from musculoskeletal pain and difficulties, in order to maintain them in a regular physical activity program targeting energy balance. Although this aligns with the actual literature regarding the effect of immersed exercise on subsequent appetitive responses in adults, these results remain preliminary. Larger as well as chronic explorations should be conducted in adolescents with obesity to better understand the potential beneficial effects of aquatic-exercise for the treatment of pediatric obesity.

Author contributions

MM, ML, TD, MD, BY: Conceptualization; CC, MM, ML, DM, BY: Data curation, Investigation; PB, DM, FG, BK, MM, ML, TD: Formal analysis; MM, MP, ML, TD,: Methodology, Project administration; ML, TD, BK, FG: Writing; ML,TD, MM, BK: Review, Editing.

Funding sources

This work has been supported by the Challenge 3 Mobility of the CAP2025 I-Site project of UCA as well as by the Health in Motion International Research Chaire of the UCA foundation and the French University Institute IUF.

Ethical statement

This work was conducted in accordance with the Helsinki declaration and all adolescents and their legal representative(s) received information sheets and signed consent forms as requested by the national ethical authorities (CPP Sud Est VI, AU1178).

Declaration of competing interest

We have no conflict of interest disclose.

Data availability

The authors do not have permission to share data.

Acknowledgements

We are grateful to all of the adolescents that participated in the study, and we thank the Center Médical Infantile de Romagnat for their generous support.

References

Andrade, L. S., Botton, C. E., David, G. B., Pinto, S. S., Häfele, M. S., & Alberton, C. L. (2022). Cardiorespiratory parameters comparison between incremental protocols performed in aquatic and land environments by healthy individuals: A systematic review and meta-analysis. *Sports Medicine.* https://doi.org/10.1007/s40279-022-01687-y

Bake, T., Peris-Sampedro, F., Wáczek, Z., Ohlsson, C., Pálsdóttir, V., Jansson, J. O., et al. (2021). The gravitostat protects diet-induced obese rats against fat accumulation and weight gain. *Journal of Neuroendocrinology, 33*(8), Article e12997. https://doi.org/10.1111/jne.12997

Brunault, P., Rabemampianina, I., Apfeldorfer, G., Ballon, N., Couet, C., Réveillère, C., … El-Hage, W. (2015). The Dutch Eating Behavior Questionnaire: Further psychometric validation and clinical implications of the French version in normal weight and obese persons. *Presse Medicale, 44*(12 Pt 1), e363–e372. https://doi.org/10.1016/j.lpm.2015.03.028

Cole, T. J., Bellizzi, M. C., Flegal, K. M., & Dietz, W. H. (2000). Establishing a standard definition for child overweight and obesity worldwide: International survey. *BMJ, 320*(7244), 1240–1243. https://doi.org/10.1136/bmj.320.7244.1240

Crabtree, D. R., & Blannin, A. K. (2015). Effects of exercise in the cold on Ghrelin, PYY, and food intake in overweight adults. *Medicine & Science in Sports & Exercise, 47*(1), 49–57. https://doi.org/10.1249/MSS.0000000000000391

Craig, C. L., Marshall, A. L., Sjöström, M., Bauman, A. E., Booth, M. L., Ainsworth, B. E., … Oja, P. (2003). International physical activity questionnaire: 12-country reliability and validity. *Medicine & Science in Sports & Exercise, 35*(8), 1381–1395. https://doi.org/10.1249/01.MSS.0000078924.61453.FB

Drapeau, V., Blundell, J., Therrien, F., Lawton, C., Richard, D., & Tremblay, A. (2005). Appetite sensations as a marker of overall intake. *British Journal of Nutrition, 93*(2), 273–280. https://doi.org/10.1079/bjn20041312

Fearnbach, S. N., Masterson, T. D., Schlechter, H. A., Loken, E., Downs, D. S., Thivel, D., et al. (2017). Perceived exertion during exercise is associated with children's energy intake. *Medicine & Science in Sports & Exercise, 49*(4), 785–792. https://doi.org/10.1249/MSS.0000000000001165

Fillon, A., Beaulieu, K., Miguet, M., Bailly, M., Finlayson, G., Julian, V., … Thivel, D. (2020). Delayed meal timing after exercise is associated with reduced appetite and energy intake in adolescents with obesity. *Pediatr Obes, 15*(9), Article e12651. https://doi.org/10.1111/ijpo.12651

Imbeault, P., Saint-Pierre, S., Alméras, N., & Tremblay, A. (1997). Acute effects of exercise on energy intake and feeding behaviour. *British Journal of Nutrition, 77*(4), 511–521. https://doi.org/10.1079/bjn19970053

Irandoust, K., Taheri, M., H'mida, C., Neto, G. R., Trabelsi, K., Ammar, A., … Knechtle, B. (2021). Exergaming and aquatic exercises affect lung function and weight loss in obese children. *Int J Sports Med, 42*(6), 566–572. https://doi.org/10.1055/a-1289-9307

Jansson, J. O., Palsdottir, V., Hägg, D. A., Schéle, E., Dickson, S. L., Anesten, F., … Ohlsson, C. (2018). Body weight homeostat that regulates fat mass independently of leptin in rats and mice. *Proceedings of the National Academy of Sciences of the United States of America, 115*(2), 427–432. https://doi.org/10.1073/pnas.1715687114

King, J. A., Wasse, L. K., & Stensel, D. J. (2011). The acute effects of swimming on appetite, food intake, and plasma acylated ghrelin. *Journal Obes, 2011*. https://doi.org/10.1155/2011/351628

Lopera, C. A., da Silva, D. F., Bianchini, J. A., Locateli, J. C., Moreira, A. C., Dada, R. P., … Nardo, N. (2016). Effect of water- versus land-based exercise training as a component of a multidisciplinary intervention program for overweight and obese adolescents. *Physiology and Behavior, 165*, 365–373. https://doi.org/10.1016/j.physbeh.2016.08.019

Masurier, J., Mathieu, M. E., Fearnbach, S. N., Cardenoux, C., Julian, V., Lambert, C., … Thivel, D. (2018). Effect of exercise duration on subsequent appetite and energy intake in obese adolescent girls. *International Journal of Sport Nutrition and Exercise Metabolism, 28*(6), 593–601. https://doi.org/10.1123/ijsnem.2017-0352

Metz, L., Isacco, L., Beaulieu, K., Fearnbach, S. N., Pereira, B., Thivel, D., et al. (2021). Cold-water effects on energy balance in healthy women during aqua-cycling. *International Journal of Sport Nutrition and Exercise Metabolism, 31*(3), 236–243. https://doi.org/10.1123/ijsnem.2020-0177

Metz, L., Isacco, L., Fearnbach, N., Pereira, B., Thivel, D., & Duclos, M. (2021). Energy intake and appetite sensations responses to aquatic cycling in healthy women: The WatHealth study. *Nutrients, 13*(4). https://doi.org/10.3390/nu13041051

Metz, L., Isacco, L., Miguet, M., Genin, P., Thivel, D., & Duclos, M. (2021). Comparing the effects of immersed versus land-based high-intensity interval cycling on energy intake, appetite sensations and perceived exertion among healthy men. *Perceptual & Motor Skills, 128*(4), 1569–1585. https://doi.org/10.1177/00315125211007345

Miguet, M., Fillon, A., Khammassi, M., Masurier, J., Julian, V., Pereira, B., … Thivel, D. (2018). Appetite, energy intake and food reward responses to an acute High Intensity Interval Exercise in adolescents with obesity. *Physiology and Behavior, 195*, 90–97. https://doi.org/10.1016/j.physbeh.2018.07.018

Miguet, M., Masurier, J., Chaput, J. P., Pereira, B., Lambert, C., Dâmaso, A. R., … Thivel, D. (2019). Cognitive restriction accentuates the increased energy intake response to a 10-month multidisciplinary weight loss program in adolescents with obesity. *Appetite, 134*, 125–134. https://doi.org/10.1016/j.appet.2018.12.015

Nemet, D., Arieli, R., Meckel, Y., & Eliakim, A. (2010). Immediate post-exercise energy intake and macronutrient preferences in normal weight and overweight pre-pubertal children. *International Journal of Pediatric Obesity, 5*(3), 221–229. https://doi.org/10.3109/17477160903311538

O'Malley, G., Ring-Dimitriou, S., Nowicka, P., Vania, A., Frelut, M. L., Farpour-Lambert, N., … Thivel, D. (2017). Physical activity and physical fitness in pediatric obesity: What are the first steps for clinicians? Expert conclusion from the 2016 ECOG workshop. *Int J Exerc Sci, 10*(4), 487–496.

Oustric, P., Beaulieu, K., Casanova, N., O'Connor, D., Gibbons, C., Hopkins, M., … Finlayson, G. (2021). Food liking but not wanting decreases after controlled intermittent or continuous energy restriction to $\geq$5% weight loss in women with overweight/obesity. *Nutrients, 13*(1). https://doi.org/10.3390/nu13010182

Pélissier, L., Julian, V., Beaulieu, K., Siroux, J., Boscaro, A., Fillon, A., … Thivel, D. (2022). Effect of acute dietary- versus combined dietary and exercise-induced energy deficits on subsequent energy intake, appetite and food reward in adolescents with obesity. *Physiology and Behavior, 244*, Article 113650. https://doi.org/10.1016/j.physbeh.2021.113650

Rocha, J., Paxman, J., Dalton, C., Winter, E., & Broom, D. (2015). Effects of an acute bout of aerobic exercise on immediate and subsequent three-day food intake and energy expenditure in active and inactive pre-menopausal women taking oral contraceptives. *Appetite, 89*, 183–191. https://doi.org/10.1016/j.appet.2015.02.005

Rowland, T. W. (1993). Does peak VO2 reflect VO2max in children?: Evidence from supramaximal testing. *Medicine & Science in Sports & Exercise, 25*(6), 689–693.

Schubert, M. M., Desbrow, B., Sabapathy, S., & Leveritt, M. (2013). Acute exercise and subsequent energy intake. A meta-analysis. *Appetite, 63*, 92–104. https://doi.org/10.1016/j.appet.2012.12.010

Shorten, A. L., Wallman, K. E., & Guelfi, K. J. (2009). Acute effect of environmental temperature during exercise on subsequent energy intake in active men. *American Journal of Clinical Nutrition, 90*(5), 1215–1221. https://doi.org/10.3945/ajcn.2009.28162

Thackray, A. E., Willis, S. A., Sherry, A. P., Clayton, D. J., Broom, D. R., Demashkieh, M., … King, J. A. (2020). An acute bout of swimming increases post-exercise energy intake in young healthy men and women. *Appetite, 154*, Article 104785. https://doi.org/10.1016/j.appet.2020.104785

Thivel, D., Genin, P. M., Mathieu, M. E., Pereira, B., & Metz, L. (2016). Reproducibility of an in-laboratory test meal to assess ad libitum energy intake in adolescents with obesity. *Appetite, 105*, 129–133. https://doi.org/10.1016/j.appet.2016.05.028

Thivel, D., Metz, L., Julian, V., Isacco, L., Verney, J., Ennequin, G., … King, J. A. (2021). Diet- but not exercise-induced iso-energetic deficit induces compensatory appetitive responses. *European Journal of Clinical Nutrition, 75*(10), 1425–1432. https://doi.org/10.1038/s41430-020-00853-7

Thivel, D., Metz, L., Julien, A., Morio, B., & Duché, P. (2014). Obese but not lean adolescents spontaneously decrease energy intake after intensive exercise. *Physiology and Behavior, 123*, 41–46. https://doi.org/10.1016/j.physbeh.2013.09.018

Ueda, S. Y., Nakahara, H., Kawai, E., Usui, T., Tsuji, S., & Miyamoto, T. (2018). Effects of walking in water on gut hormone concentrations and appetite: Comparison with walking on land. *Endocr Connect, 7*(1), 97–106. https://doi.org/10.1530/EC-17-0323

White, L. J., Dressendorfer, R. H., Holland, E., McCoy, S. C., & Ferguson, M. A. (2005). Increased caloric intake soon after exercise in cold water. *International Journal of Sport Nutrition and Exercise Metabolism, 15*(1), 38–47. https://doi.org/10.1123/ijsnem.15.1.38

Yaghoubi, M., Fink, P. W., Page, W. H., Heydari, A., & Shultz, S. P. (2019). Kinematic comparison of aquatic- and land-based stationary exercises in overweight and normal weight children. *Pediatric Exercise Science, 31*(3), 314–321. https://doi.org/10.1123/pes.2018-0188