British Journal of Nutrition (2017), **117**, 602–610
doi:10.1017/S0007114515004201

The effects of a mid-morning snack and moderate-intensity exercise on acute appetite and energy intake in 12–14-year-old adolescents

Joanna L. Varley-Campbell[1], Melanie S. Moore[2] and Craig A. Williams[1]*

[1]*Children's Health and Exercise Research Centre, Sport and Health Sciences, St Luke's Campus, University of Exeter, Heavitree Road, Exeter EX1 2LU, UK*

[2]*School of Health Professions, Plymouth University, Plymouth, Devon PL6 8BH, UK*

(Submitted 30 November 2014 – Final revision received 11 June 2015 – Accepted 21 September 2015 – First published online 2 November 2015)

Abstract

Energy intake (EI) and energy expenditure (EE) should not be considered independent entities, but more an inter-connected system. With increased physical activity and reduced snacking initiatives as prevalent Public Health measures, any changes to subsequent EI from these recommendations should be monitored. The aim of this study was to investigate changes in acute EI and appetite over four conditions: (1) a control condition with no snack and no exercise (CON); (2) a snack condition (+1 MJ; SK); (3) a moderate-intensity cycling exercise condition (−1 MJ; EX); and finally (4) both snack and exercise condition (+1 MJ, −1 MJ; EXSK). Acute changes in appetite (visual analogue scale) and lunchtime EI (*ad libitum* pizza meal) were recorded in twenty boys and eighteen girls (12–13 years). Lunch EI was not significantly different between conditions or sexes ($P > 0{\cdot}05$). Relative EI was calculated, where the energy manipulation (+1 MJ from the snack or −1 MJ from the exercise) was added to lunchtime EI. Relative EI indicated no significant differences between the sexes ($P > 0{\cdot}05$); however, in the EX condition, relative EI was significantly lower ($P < 0{\cdot}001$) compared with all other conditions. Appetite increased significantly over time ($P < 0{\cdot}001$) and was significantly higher in the CON and EX conditions compared with the SK and EXSK conditions. No significant sex differences were found between conditions. When aiming to evoke an acute energy deficit, increasing EE created a significantly larger relative energy deficit than the removal of the mid-morning snack. Sex was not a confounder to influence EI or appetite between any of the conditions.

Key words: Eating behaviours: Sex differences: Preload meals: Mood

Data from the Health Survey for England[1] indicated the prevalence of overweight and obesity in children aged 11–15 years to be 32·5 %, whereas in the same age group physical activity guidelines were only being met by approximately 14 %. If increasing physical activity is a government-based target to help reduce the prevalence of overweight and obesity in children, it is important that any subsequent changes to eating behaviours, which may impact upon energy balance, be considered.

There are two components that make up energy balance, energy intake (EI) and energy expenditure (EE), which should not be considered as independent entities. Snacking of energy-dense foods, which is common in adolescents[2], impacts energy balance by increasing EI and potentially creating an energy surplus. Conversely, physical activity, particularly in the form of structured exercise, directly affects the energy balance by increasing EE and potentially creating an energy deficit. Both EI and EE are now more commonly considered an inter-connected system[3].

Evidence on whether increasing EE through imposed acute bouts of exercise will change subsequent EI in lean children and adolescents is still inconclusive[4]. However, it has been proposed that acute increases in physical activity are more likely to impact energy balance through an indirect change in appetite and food intake, as opposed to an increase in EE[4]. Similarly, servings per d of snack foods are not necessarily an independent determinant of weight gain in children and adolescents[5]. Manipulations to both EI and EE within the same protocol has only been performed once in boys aged 9–11 years who were recruited into a laboratory-controlled study in which the preload meal was a glucose drink and the exercise was moderate treadmill exercise[6]. Elucidating the understanding of whether EI alters acutely in response to an increase in EI (mid-morning snack) or an increase in EE (moderate-intensity exercise) or in combination within the school setting is a novel area of interest.

Previous research into the acute effects of exercise on EI and subjective appetite feelings in the lean paediatric population has predominantly been performed in the controlled environment of a laboratory[6–11]. Consequently, the findings of these studies are limited by their generalisability. To our knowledge

Abbreviations: EE, energy expenditure; EI, energy intake.

* **Corresponding author:** Professor C. A. Williams, fax +44 1392 724726, email c.a.williams@exeter.ac.uk

only Rumbold *et al*. have conducted this type of research in a school environment[12]. However, they lacked some precision in their EI measures because EI was recorded through food diaries. The impact of exercise findings on EI and appetite is equivocal, possibly due to variations in the intensity, duration and type of exercise performed[7–13]. Conducting the research in a more habitual environment for children and adolescents – for example, within a school – will result in an increase in the external and ecological validity of the findings.

Therefore, the aim of the present study was to investigate whether an energy-controlled mid-morning snack (1 MJ), an increased EE (1 MJ) from a moderate-intensity exercise session, or a combined protocol (+1 MJ and −1 MJ) can alter acute subjective feelings of appetite. The second aim was to determine whether acute lunchtime EI would be altered between conditions. We hypothesised that when compared with the control condition, following the snack condition, lunchtime EI and feelings of appetite would reduce; following the moderate-intensity exercise condition, lunchtime EI and feelings of appetite would increase; and following the exercise and snack condition, lunchtime EI and feelings of appetite would not significantly change. Consequently, we hypothesised that relative EI would not be significantly different between any of the four conditions.

Methods

Participants

In all, twenty boys aged 12·9 (SD 0·3) years and eighteen girls aged 13·1 (SD 0·2) years, following an invitational meeting at their school in the South West of England, volunteered to participate in the study. Two additional girls were originally recruited but withdrew their consent after the first visit because of their inability to commit to the testing schedule and were therefore excluded from all analyses. Power calculations were performed using EI data from both a paediatric EI preload study[8] and an exercise study[7] to yield a sample size range suitable to incorporate both energy balance manipulations within this study. The EI preload arm of this study estimated a sample size of 6[8], whereas the increase in the EE arm of this study estimated a sample size of 38[7]. The Institutional Ethics Committee approved the study, and once fully informed of all procedures written informed consent was obtained from the caregivers and informed assent from the adolescents. A brief medical history and food intolerance questionnaire were completed and used to exclude participants who had a history of diabetes or other metabolic disorders known to affect the intermediary metabolism.

Design

Changes in EI over the lunchtime meal and feelings of appetite over the course of the morning were compared between adolescent boys and girls in four conditions using a within-subjects design. The order in which the participants completed each of the four conditions was randomised. The four conditions were as follows: (1) a control condition of no snack and no exercise (CON); (2) a snack condition in which a mid-morning snack was consumed (totalling an EI of 1 MJ; SK); (3) an exercise condition in which moderate-intensity exercise was performed (totalling an EE of 1 MJ; EX); and finally (4) a condition in which both a snack was consumed and moderate-intensity exercise was performed (totalling EI of 1 MJ and EE of 1 MJ; EXSK).

Time	08.00 hours	08.55 hours	09.55 hours	10.55 hours	11.15 hours	12.15 hours	13.15 hours
CON	Breakfast	Lessons	Lessons	No snack	Lessons	Lessons	Lunch
EX	Breakfast	Lessons	Lessons	No snack	Exercise	Lessons	Lunch
SK	Breakfast	Lessons	Lessons	Snack	Lessons	Lessons	Lunch
EXSK	Breakfast	Lessons	Lessons	Snack	Exercise	Lessons	Lunch

Fig. 1. Schematic of the protocol for each condition. CON, control; EX, exercise; SK, snack; EXSK, exercise and snack.

Participants attended the research centre on one occasion in groups of four for preliminary measurements, followed by four visits to a temporary laboratory setup within the school to complete the four conditions. Each participant from the group of four completed a different condition to allow independent data collection between the conditions. Testing where possible occurred on the same day of the week, with a minimum of 7 d to a maximum of 28 d between visits. A schematic of the protocol for each condition is depicted in Fig. 1. The preliminary visit at the research centre consisted of the collection of anthropometric measures, collection of an eating behaviour questionnaire (Dutch eating behaviour questionnaire for children)[14], food selections for the subsequent experimental days, a VO_{2peak} test, resting EE measurements and a steady-state exercise test.

Anthropometric data collection

Stature and sitting stature were measured to the nearest 0·01 m (Seca stadiometer; Seca) with no shoes. Body weight was measured to the nearest 0·1 kg (Hampel digital scales; Hampel Electronics Co.) in light sports clothing and no shoes. Body density was estimated by air displacement plethysmography (BOD POD; Life Measurements Instruments), and the estimated maturity status was calculated[15]. Anthropometric characteristics of the participants are reported in Table 2.

Resting energy expenditure

Participants wearing a face mask sat quietly in a chair while their expired air was collected breath by breath through a respiratory gas analyser (Cortex Metalyzer 3B and Metasoft version 2.1 software) for a 10 min duration. VO_2 and expired carbon dioxide were calculated from the expired air samples and averaged per second to calculate the estimated EE[16].

Exercise tests

An incremental ramp test for determination of VO_{2peak} was completed on a cycle ergometer (Lode Excalibur Sport V2; Lode BV). Following a 3 min warm-up at 25 W, the work rate was increased continuously by 25 W/min until volitional exhaustion.

A heart rate (HR) monitor was fitted to the adolescents (Polar heart rate monitor; Polar Electro). HR was continually monitored throughout the test, being manually recorded over the last 10 s of each minute, together with a rating of perceived exertion (RPE) using the 1–10 Pictorial Children's Effort Rating Table scale[17]. Participants were actively encouraged until exhaustion. Expired air samples were collected breath by breath throughout the test, using the same equipment to measure resting EE. Volitional exhaustion was determined if participants were unable to maintain the pedal cadence (70 (SD 5) rpm) despite verbal encouragement. In addition, two of the following subjective indicators of maximal effort were met: respiratory exchange ratio (RER) reached a value >1·1, maximal HR was ≥95 % of age-predicted maximum (220 chronological age), RPE was >9, or the subject demonstrated clear subjective symptoms of fatigue. All participants satisfied these criteria. VO_{2peak} was taken as the absolute highest value over a 10 s average before cessation of the exercise test. A minimum of 45 min rest was then provided before the steady-state exercise commenced. Using the data collected from the VO_{2peak} test, 80 % of gaseous exchange threshold (GET) was calculated for each participant[18]. The work rate required to induce 80 % GET when cycling at 60 rpm was calculated and then set on the ergometer. The participants then cycled for 6 min at this work rate. Expired air samples were collected as before and averaged per second to calculate the estimated EE. From the average EE per minute when resting and when exercising at 80 % GET, the net increase in EE per minute was calculated from subtracting the resting EE from the exercising EE. The duration required to expend 1 MJ of energy was then calculated for use within the exercising experimental conditions.

Food choices

Finally on the preliminary day participants were asked to select one from the following food choices for each eating occasion in the experimental condition (Table 1). Once selections had been made, participants could not alter their options between conditions.

Experimental conditions

A temporary laboratory was setup in a classroom within the school. Participants arrived at 08.00 hours following an overnight fast, a prerequisite that was verbally confirmed upon arrival. On the morning of the first experimental day, breakfast quantity was self-selected. Breakfast intake was weighed (Salter Aquatronic Stainless Steel Digital Kitchen Scales; Salter) and recorded so that the amount could be replicated in the remaining three experimental conditions. Breakfast intake was not included in any of the EI measures, as it remained a constant throughout.

Following breakfast, a mood questionnaire was completed (Positive and Negative Affect Scale for Children (PANAS-C)[19]) along with the first collection of appetite scores. Appetite scores were collected at seven time points throughout the testing morning: after breakfast (08.35 hours), between the first and second lesson (09.55 hours), before break time (10.55 hours), after break time (11.15 hours), between the third and fourth lesson (12.15 hours), before lunch (13.15 hours) and after lunch (13.55 hours). Hunger, fullness and prospective consumption were measured on a visual analogue scale (VAS) 100 mm line[7,10]. The response to the question 'How hungry are you now?' was anchored on the left by 'not at all' and on the right by 'very hungry'. 'How full do you feel?' was anchored on the left by 'empty' and on the right by 'very full'. Prospective consumption, 'how much could you eat right now?', was anchored on the left by 'nothing' and on the right by 'lots and lots'.

Participants were given a 500 ml bottle of water to take with them to lessons, with any refills being recorded by the participant in their data booklet. The participants were reminded not to eat or drink anything that was not provided by the researchers before attending their first and second lessons as normal. If physical activity was scheduled within their timetable, participants were excused from the lesson and went to the library for private study.

All participants returned to the temporary laboratory classroom at break time (10.55–11.15 hours) irrespective of condition to collect and eat their snack (as appropriate to the condition: SK and EXSK) or wait with the others. This also allowed the

Table 1. Meal selection options, one from each category could be chosen

	Choices	kJ/100 g
Breakfast	Mini Max Original® (Kellogg Marketing and Sales Company UK Ltd)	1565
	Mini Max Chocolate® (Kellogg Marketing and Sales Company UK Ltd)	1590
	Rice Krispies® (Kellogg Marketing and Sales Company UK Ltd)	1626
	Semi-skimmed milk	202
Mid-morning snack	1 × packet Iced Gems® (Jacob's Bakery), 1 × packet mini chocolate animal biscuits (Cadburys, Burton's Biscuits Co.), 1 × Original Cheese String® (Kerry Foods) (total intake 67 g)	1542
	1 × packet Iced Gems®, 1 × packet mini chocolate biscuits, 1 × Mini Babybel® (original, Fromageries Bel) (total intake 67 g)	1531
	1 × 2 finger chocolate bar (Nestlé KitKat), 1 × strawberry fruit flakes (Fruit Bowl, Stream Foods Ltd) Babybel® (light), 1 × milk chocolate finger biscuit (Cadburys, Burton's Biscuits Co.) (total intake 67 g)	1493
	2 × Digestive Biscuits (McVitie's), 1 × Dairylea Dunker® (Breadsticks, Mondelez UK) (total intake 77 g)	1319
	1 × Fromage Frais Strawberry Pouch (Sainsbury's Supermarket), 1 × packet yogurt raisins (Stream Foods Ltd), 1 × milk chocolate finger biscuit (total intake 126 g)	810
Lunch	Four cheese pizza (Chicago Town Deep Dish)	1219
	Ham and pineapple pizza (Chicago Town Deep Dish)	1064
	Pepperoni pizza (Chicago Town Deep Dish)	1249
	Chicken melt pizza (Chicago Town Deep Dish)	1110

British Journal of Nutrition

researcher an opportunity to ensure that the VAS was being recorded at the appropriate time points, as the onus for completion was on the adolescents for some of the time points. Options were provided for the mid-morning snack so that the energy and macronutrient compositions were similar between choices. Energy content ranged from 1000 to 1033 kJ, carbohydrate ranged from 51 to 55 %, protein from 11 to 12 % and fat from 33 to 37 %. The macronutrient compositions are similar to the average macronutrient requirements for adolescents of this age group[20].

Following the morning break, those exercising (EX and EXSK conditions) stayed in the classroom, whereas those not exercising returned to their lessons. All exercise sessions ceased 5 min before the end of the third lesson (12.10 hours); therefore, depending on the duration of exercise required to expend 1 MJ of energy, the start time differed accordingly. Therefore, for each child there was always 65 min between exercise cessation and the provision of the lunch test meal. The exercise duration ranged from 31 to 56 min (mean 44 (SEM 7) min). The cycling exercise was performed on a Monark 827e friction-braked cycle ergometer within the classroom (Monark Exercise AB) that was calibrated to the cycle ergometer used at the research centre on the preliminary day.

Within the school's normal lunch break (13.15–13.55 hours), participants arrived at the temporary laboratory classroom for their lunch and were given a plate of two 5" pizzas cut into sixteen bite-sized pieces. Participants were asked to eat until comfortably full and had the duration of the lunch break in which to eat. If the first plate was finished, another plate of pizza was provided and so on until full. Weighed intake of each plate was recorded so that EI could be calculated. Participants ate their pizzas together in their groups of four, as this was deemed most like their habitual lunchtime environment of eating together with their peers in the dinner hall. Following the final VAS of the condition, participants were able to return to afternoon lessons.

Data and statistical analysis

Relative EI was calculated for each condition (EI +1 MJ for the SK and EXSK conditions and −1 MJ for the EX and EXSK condition). By calculating relative EI, the manipulation to the daily energy balance was taken into consideration. Descriptive data are presented as means and standard deviations, unless otherwise stated.

The participants' physical and physiological characteristics were compared between sexes using an independent samples *t* test. EI and relative EI were compared between conditions and sex using 2×4 mixed model ANOVA. To estimate the effect size, Cohen's *d* was calculated. Appetite scores over time were compared between conditions and sex over time using a $2 \times 4 \times 7$ mixed model ANOVA.

Pearson's correlations were determined between eating behaviours (emotional, external and restrained) and both EI and relative EI, separated by sex. Pearson's correlations were also run between the positive and negative affect score calculated from the PANAS for EI, irrespective of condition but separated by sex.

Significant differences within the ANOVA were investigated using *post hoc* Bonferroni-corrected pairwise comparisons. A Greenhouse–Geisser correction factor was also applied if Mauchly's test of sphericity was violated. Statistical analyses were conducted using the Statistical Package for Social Sciences (version 20.0; SPSS Inc.). An α level $P < 0{\cdot}05$ was accepted to indicate statistical significance.

Results

Participant age, physical characteristics, maturity status, aerobic capacity and eating behaviours are given in Table 2.

Energy intake

Mean values with their standard errors for lunch EI for both sexes over the four conditions are displayed in Fig. 2(a). There were no significant differences between conditions ($F_{2{\cdot}446,88{\cdot}045} = 1{\cdot}602$; $P = 0{\cdot}202$), sex ($F_{1,36} = 2{\cdot}76$; $P = 0{\cdot}105$) or interaction between condition × sex ($F_{2{\cdot}446,88{\cdot}045} = 0{\cdot}601$; $P = 0{\cdot}583$).

Relative energy intake

The mean values with their standard errors relative EI values for both sexes over the four conditions are displayed in Fig. 2(b).

Table 2. Participants' physical and physiological characteristics (Mean values and standard deviations)

	Boys (*n* 20)		Girls (*n* 18)	
	Mean	SD	Mean	SD
Age (years)	12·9	0·3	13·1	0·2
Stature (m)	1·58	0·08	1·60	0·05
Weight (kg)	45·9	9·1	47·2	5·4
BMI (kg/m^2)	15·3	2·3	18·4	2·1
Body fat (%)	14·8	7·3	16·5	3·5
Estimated maturity status from PHV (years)	– 0·99*	0·58	1·03	0·32
VO_{2peak} (ml/kg per min)	49·8*	10·5	39·7	5·5
Emotional eating	1·31	0·56	1·35	0·56
Restrained eating	1·75	0·57	1·80	0·53
External eating	2·01	0·55	1·95	0·41

PHV, peak height velocity.
* Significant differences between sexes ($P < 0{\cdot}05$).

https://doi.org/10.1017/S0007114515004201 Published online by Cambridge University Press

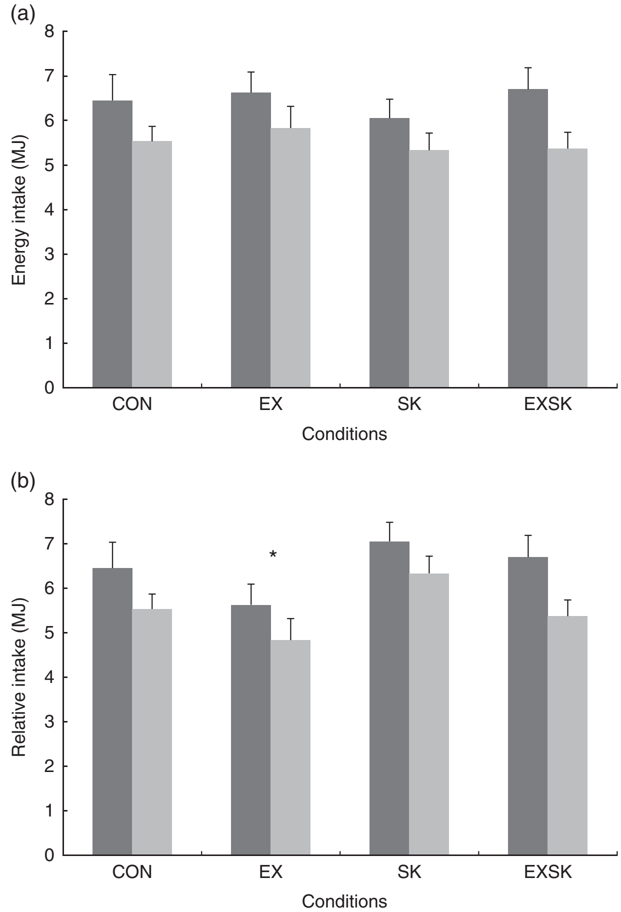

Fig. 2. Lunch energy intake (a) and relative energy intake (b) for each condition for boys (■) and girls (■). Values are means (boys (*n* 20); girls (*n* 18)), with their standard errors represented by vertical bars. There were no significant differences between conditions or between sexes ($P>0·05$) for energy intake. Relative energy intake in the snack condition was significantly lower than all other conditions for both sexes (*$P<0·05$). CON, control; EX, exercise; SK, snack; EXSK, exercise and snack.

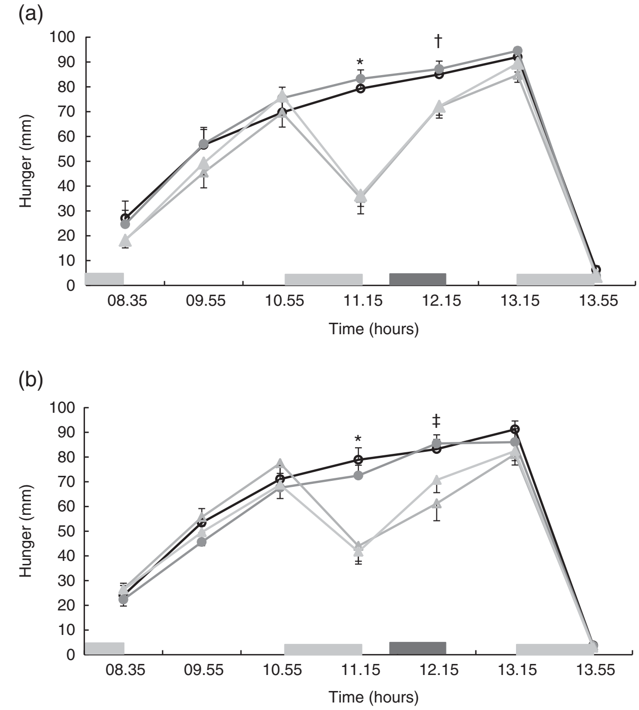

Fig. 3. Values are means, with their standard errors, visual analogue scale for expressions of hunger in boys (a, *n* 20) and girls (b, *n* 18) for each condition. Very hungry = 100. * Significant difference for CON and EX conditions compared with SK and EXSK conditions ($P<0·001$). † Significant difference for CON compared with SK and for EX compared with SK and EXSK ($P<0·05$). ‡ Significant difference for CON and EX compared with SK ($P<0·002$). ■, Eating occasion; ■, exercise bout; CON (—○—), control; EX (—●—), exercise; SK (—△—), snack; EXSK (—▲—), exercise and snack.

There was a significant difference between conditions ($F_{2·446,88·045}=11·581$; $P<0·001$). However, there were no significant differences between sexes ($F_{1,36}=2·76$; $P=0·105$), nor in the interaction between condition × sex ($F_{2·446,88·045}=0·601$; $P=0·583$). *Post hoc* analysis indicated that relative EI was significantly higher in the CON, SK and EXSK conditions when compared with the EX condition (mean difference 0·8 (SEM 0·3), 1·5 (SEM 0·2) and 0·8 (SEM 0·2) MJ, respectively). Subsequent effect size analysis for relative EI between CON and EX was $d=0·37$ and that between CON and SK was $d=0·35$.

Water intake

For water intake, there was a significant difference between conditions ($F_{2·274,81·854}=25·056$; $P<0·001$). However, there were no significant differences between sexes ($F_{1,36}=1·036$; $P=0·316$), nor was there a significant condition × sex interaction ($F_{2·274,81·854}=1·136$; $P=0·331$). *Post hoc* analysis indicated a significant increase in water intake in the EX condition (1089 (SEM 165) ml for boys and 838 (SEM 106) ml for girls) when compared with CON (415 (SEM 60) ml for boys and 444 (SEM 79) ml for girls) and SK ($P<0·001$, 513 (SEM 67) ml for boys and 480 (SEM 62) ml for girls). There was also a significant increase in water intake in the EXSK condition (1037 (SEM 125) ml for boys and 894 (SEM 56) ml for girls) when compared with CON and SK ($P<0·001$). There were no significant differences in water intake between CON and SK and between EX and EXSK ($P>0·05$).

Appetite

Mean ratings of hunger are depicted in Fig. 3(a) (boys) and (b) (girls), fullness in Fig. 4(a) (boys) and (b) (girls) and prospective consumption in Fig. 5(a) (boys) and (b) (girls). A significant effect of time, condition and condition × time interaction was found for all three appetite scores ($P<0·002$). For all three appetite scores, there were no significant differences between sexes, nor for the interactions of condition × sex, time × sex and condition × time × sex ($P>0·05$).

Post hoc analysis indicated that hunger and prospective consumption were significantly higher, whereas fullness was significantly lower, in CON compared with SK and EXSK ($P<0·005$). Hunger and prospective consumption were also significantly higher, whereas fullness was significantly lower in EX compared with SK and EXSK ($P<0·02$).

Various significant differences were observed between conditions at specific time points (primarily 11.15 hours and

https://doi.org/10.1017/S0007114515004201 Published online by Cambridge University Press

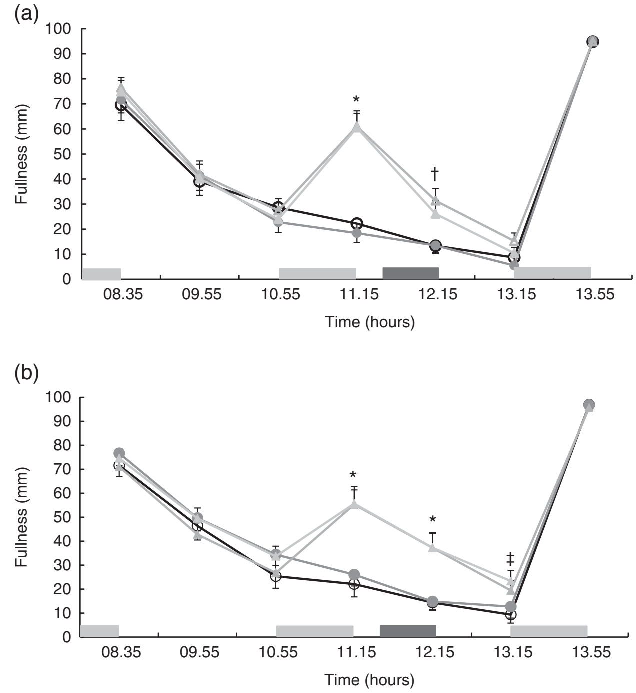

Fig. 4. Values are means, with their standard errors, visual analogue scale for expressions of fullness in boys (a, *n* 20) and girls (b, *n* 18) for each condition. Very full = 100. * Significant difference for CON and EX compared with SK and EXSK ($P < 0.002$). † Significant difference for CON and EX compared with SK ($P < 0.006$). ‡ Significant difference between CON compared with SK and EXSK ($P < 0.05$). ▪, Eating occasion; ▪, exercise bout; CON (—○—), control; EX (—●—), exercise; SK (—△—), snack; EXSK (—▲—), exercise and snack.

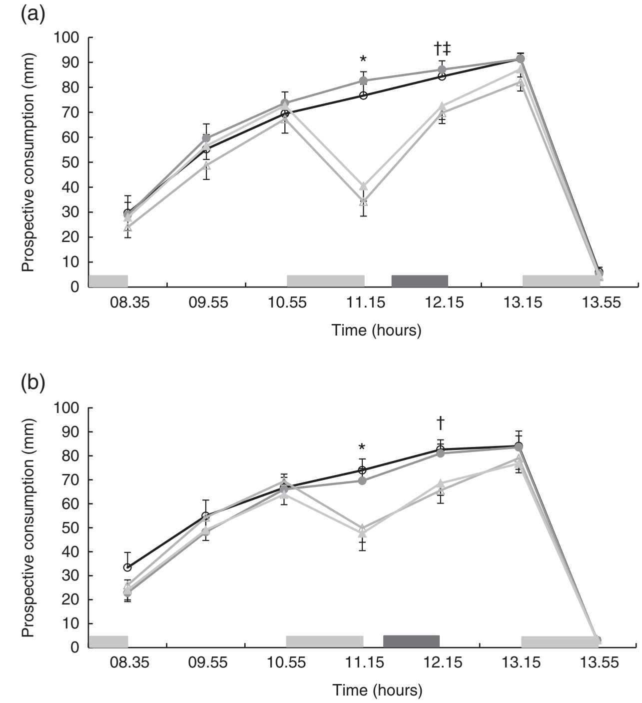

Fig. 5. Values are means, with their standard errors, visual analogue scale for expressions of fullness in boys (a, *n* 20) and girls (b, *n* 18) for each condition. Very full = 100. * Significant difference for CON and EX compared with SK and EXSK ($P < 0.03$). † Significant difference for CON and EX compared with SK ($P < 0.014$). ‡ Significant difference between EX and EXSK ($P = 0.017$). ▪, Eating occasion; ▪, exercise bout; CON (—○—), control; EX (—●—), exercise; SK (—△—), snack; EXSK (—▲—), exercise and snack.

12.15 hours) (see Fig. 3(a) and (b), 4(a) and (b), 5(a) and (b) for further information).

Eating behaviour

There were no significant correlations between eating behaviours (emotional, restrained and external) and EI or relative EI in boys. A significant moderate positive correlation was found in girls between emotional eating and EI in the EXSK condition (r 0·536; $P = 0.022$) and between external eating and EI in both the CON (r 0·635; $P = 0.005$) and EXSK conditions (r 0·620; $P = 0.006$).

Daily emotion

There were no significant correlations between either the positive or negative affect score and EI in boys ($P > 0.05$). There was a significant but weak correlation between the positive (r 0·258; $P = 0.029$) but not the negative (r 0·078; $P = 0.512$) affect score and EI in girls.

Discussion

The primary aim of this study was to investigate whether a mid-morning snack or an imposed bout of moderate-intensity exercise, or both, would impact acute appetite and/or EI. The intervention had no effect on acute lunchtime EI, as there were no significant differences between conditions. However, relative EI was found to be significantly lower in the EX condition when compared with all other conditions (CON, SK and EXSK), indicating that over the course of the morning (5·5 h) a mean acute energy deficit was created by the bout of exercise. Therefore, the hypothesis regarding acute changes following the EX condition was rejected for both EI and relative EI. The second hypothesis regarding acute changes to EI following the SK condition was rejected for EI but accepted for relative EI. Finally, the third hypothesis regarding acute changes to EI following the EXSK condition was accepted for both EI and relative EI. The second aim of the study was to investigate whether the conditions altered acute feelings of appetite. Overall appetite was significantly higher in the CON and EX conditions when compared with the SK and EXSK conditions, but there were no significant differences between CON and EX or between SK and EXSK. Therefore, all hypotheses relating to appetite were accepted. In contrast to previous studies, which have used a laboratory setting, this is the first time such a study has been taken into the habitual environment of a school, thus increasing the external validity of these findings.

Energy intake

The findings from the present study showed that children (regardless of sex) do not alter their EI in the short term in response to an imposed increase in EI (mid-morning snack,

+1 MJ) or increase in EE (cycling exercise, −1 MJ) or an increase in both EI and EE (EXSK, +1 MJ, −1 MJ), when compared with a control condition (CON, 0 MJ). Our findings support those of Hunschede *et al.*[6] with respect to no significant differences observed in EI following an exercise condition when compared with a control. However, we found no significant differences between the SK and CON conditions, which does not corroborate their findings of a significantly reduced EI following a glucose preload. These disparities are most likely due to the time-lapse difference between the provision of the test meal following the snack/glucose preload being 2 h in our study and only 1 h in that of Hunschede *et al.*[6] observing no significant differences in EI following the EXSK compared with the CON condition was of particular interest as the energy manipulations to the EXSK condition matched the energy balance from the CON condition. This result was therefore to be expected based on the designed energy matching of the conditions. Unexpectedly, neither the imposed bout of exercise nor the increased mid-morning snack significantly altered acute lunchtime EI. Potentially the energy expended from the exercise did not create a large enough deficit, unlike a similar duration of netball exercise, which expended 1·4 (SEM 0·2) MJ and was found to significantly increase EI compared with a control condition[12]. Similarly, the snack given may not have been of a big enough size (1 MJ) to significantly alter acute EI for the lunchtime meal. However, the quantity given (10–15 % of daily recommended intake[20]) would be deemed a generous-sized snack.

Relative energy intake

On the basis of results from the relative EI analysis, if an imposed less positive energy balance were an aim to help maintain body weight, then increasing daily EE would be recommended. As the imposed exercise bout (energy deficit) was not compensated for in the lunchtime meal, relative EI was significantly lower in the EX condition, resulting in an acute negative energy balance, compared with all other conditions.

Surprisingly, relative EI was not significantly higher in the SK condition when compared with the CON or EXSK conditions; that is, the addition of the snack did not result in an acute positive energy balance as might have been suggested. However, as the effect sizes and mean differences were similar between CON and EX (d = 0·37 and 0·8 MJ, respectively) and between CON and SK (d = 0·35 and 0·7 MJ, respectively), the non-significant findings could possibly be a result of an underpowering of the study. Interestingly, Muthayya *et al.*[21] demonstrated improved memory performance in children following the consumption of a mid-morning snack. The removal of a mid-morning snack would not be recommended as a method to create an energy deficit, as relative EI was unaffected by the consumption of a mid-morning snack and cognitive ability could be affected.

Water intake

Water intake was not a key variable within this study; however, it was important to monitor the intake as increase in water consumption before a meal has been shown to reduce EI[22,23]. Water intake was significantly higher for both the EX and EXSK conditions when compared with the CON and SK conditions. The increase in water intake did not appear to reduce EI, as previously suggested[22,23], as no significant differences in EI between conditions were found. Water intake was most likely increased in the EX and EXSK conditions because of the imposed exercise bout triggering a natural thirst response to rehydrate.

Appetite

The appetite baseline scores were not significantly different between the four conditions; therefore, despite the potential limitation of a repeated and standardised breakfast (as opposed to a free choice for each condition), the children started the day with similar low levels of appetite. Unsurprisingly, feelings of appetite changed throughout the test period, with participants becoming increasingly hungrier, less full and having an increased desire to eat as the morning progressed for each condition. Similarly as expected, CON and EX had increased average appetite scores compared with SK and EXSK, where the mid-morning snack suppressed appetite. Interestingly, however, the appetite suppression observed following the snack was acute, and, despite the earlier eating occasion from the mid-morning snack, appetite had returned to match scores from CON and EX immediately before lunch for the boys. For the girls, some but not all of the appetite scores had returned to match the CON and EX conditions. As primarily all participants were rating their appetite immediately before lunch the same between conditions, this observation may partially explain why there were no significant differences in EI between conditions. As the school day has a strict structure, which the children are used to, time is an important factor. Observing similar ratings of appetite between conditions immediately before lunch could be more related to the children associating this particular time as being lunchtime and subsequently associating that with increased appetite. This hypothesis would need testing in an environment where knowledge of time is concealed *v.* known school time.

Sex differences

In accordance with the only sex comparison paediatric study previously conducted[8], this study found no significant sex differences for either EI or appetite. Where sex differences have been found within the adult literature[24–27], a higher exercise intensity has been used (approximately 68–70 % VO_{2max}). Comparatively to our study, Bozinovski *et al.*[9] implemented a lower exercise intensity (exercise at ventilation threshold) for either 15 or 45 min. Therefore perhaps, it is the implementation of the lower exercise intensities that are resulting in a non-significant finding between the sexes in the paediatric population as opposed to their maturation (when compared with adults)[24–27]. This is a hypothesis that would need further exploration.

Eating behaviour and daily emotion

Large inter-subject variability for EI between conditions within similar experimental settings has previously been observed in

https://doi.org/10.1017/S0007114515004201 Published online by Cambridge University Press

both the adult[28,29] and the paediatric[7] literature. Within our study, EI ranged from 2·2 to 12·1 MJ between participants for the lunchtime meal; both extremes were observed in CON. Factors that may predict the variability between participants for EI are therefore of importance. In the present study, eating behaviours (external, emotional and restraint) and daily mood (positive and negative affect) were therefore correlated against EI. Neither eating behaviours nor daily mood significantly correlated with EI in boys. However, significant positive correlations were found for girls for both eating behaviours and daily mood. As scores for eating in response to emotion increased, so did EI in the EXSK condition. Similarly, as external eating awareness increased, so did EI in the CON and EXSK conditions. This is the first time that daily mood scores have been correlated to EI within the paediatric population. We cannot provide a rationale for the increasing EI in CON and EXSK that allied with increased emotional and external eating behaviours in girls. Further research should be conducted to investigate these relationships. The girls were also found to have a significant positive correlation between EI and positive affect score, indicating that those with a higher positive mood at the start of the day consumed more than those with a lower positive mood. Changes in hormones in adolescent girls have been strongly associated with changes in mood[30]. In particular, high levels of oestrogen in adult women have been associated with a more positive mood, whereas a lack of oestrogen has been associated with depression and negative affect[30]. As oestrogen levels change over the course of the menstrual cycle, future research should include a measure of the children's (if applicable) stage in the menstrual cycle on each experimental day. Controlling for the girls' hormone levels was not feasible for such a complex protocol, as the four experimental days would require a minimum of 16 weeks to account for the menstrual cycle. It was also thought that controlling for the menstrual cycle might negatively impact recruitment. Potentially a change in hormone levels may explain the changes in mood observed between the female participants. Increased intake when feeling positive may corroborate the previous findings of increasing EI in girls with high emotional eating behaviour scores. However, as EI was only significantly correlated to emotional eating scores in one (EXSK) of the four conditions, this finding is not conclusive and further research is warranted.

Limitations

Some limitations to the present study are worth noting. First, the precision of the amount of energy expended for both the EX and EXSK conditions needs careful interpretation. Although every effort was made to ensure that pedal cadence was met throughout the cycling bout (visual monitoring and verbal encouragement to maintain the required cadence), the energy expended from the bout of exercise was not measured on the day (as exercise took place at the school) and therefore may not have met precisely 1 MJ. However, on the basis of our pilot and steady-state trials, every attempt was made to minimise its effect and ensure that an energy deficit was induced. The association between overconsumption of highly palatable foods[31] and the provision of a highly palatable pizza test meal is a possibility. However, we do not think this to be the case. Pizza test meals have previously been used within similar paediatric research[8,9,11] and the provision of a one-item homogenised meal prevented any macronutrient satiety hierarchy associated with a mixed meal approach[32,33]. Pizza is also a meal commonly liked within the adolescent population and was quick to prepare and serve in the quantity required for the participants each day within the school setting. It was therefore deemed that a pizza test meal was an appropriate meal to provide to meet the study requirements. We acknowledge the limitation of the participants eating their lunch meal together. The social dimension of eating together may have altered the actual intake should the participants have eaten in isolation. However, in keeping with strengthening the ecological validity of the study, it was decided that eating together would be most like their habitual lunchtime environment of eating with their peers in the dinner hall. Finally, subsequent effect size calculated for the derived variables – that is, relative EI – was shown to be small ($d = 0{\cdot}32$), and therefore increasing either the precision of measurements or the sample size needs to be considered.

Conclusion

By utilising a within-subjects design method, adolescents were found not to acutely alter their intake in response to a mid-morning snack or moderate-intensity exercise bout or both. This implies that any imposed changes to acute energy balance over the course of a morning will not significantly alter lunch intake. Appetite sensations, although suppressed, following a mid-morning snack primarily returned to match appetite scores to that of the other conditions immediately before the lunch meal. These observations show that any changes to appetite before the time point, typically known as lunchtime, may become obsolete on the basis of the familiarity of increased appetite being associated with lunchtime. Recommendations to measure appetite in an environment where time and habit cannot confound the results are therefore suggested for future research.

Acknowledgements

The authors would like to acknowledge the teachers, staff and pupils from St James School, Exeter, Devon for their cooperation for the conduct of this research.

This work was supported by Kelloggs Ltd in the award of a PhD studentship to J. L. V.-C. Kelloggs Ltd had no role in the design, analysis or writing of this article.

C. A. W., M. S. M. and J. L. V.-C. formulated the research question, designed the study, and contributed to the writing, redrafting and final submission of the paper. J. L. V.-C. conducted the data collection and analysis.

The authors declare that there are no conflicts of interest.

References

1. Ryley A (2012) Children's BMI, overweight and obesity. In Health Survey for England, chapter 11. http://www.hscic.gov.uk/catalogue/PUB13218/HSE2012-Ch11-Child-BMI.pdf (accessed October 2015).

2. Savige G, MacFarlane A, Ball K, *et al.* (2007) Snacking behaviours of adolescents and their association with skipping meals. *Int J Behav Nutr Phys Act* **4**, 36.
3. Thivel D, Duche P & Morio B (2013) Energy balance in youth: an 'inter-dynamic' concept? *Br J Nutr* **109**, 581–582.
4. Thivel D, Aucouturier J, Doucet E, *et al.* (2012) Daily energy balance in children and adolescents. Does energy expenditure predict subsequent energy intake? *Appetite* **60**, 58–64.
5. Field AE, Austin SB, Gillman MW, *et al.* (2004) Snack food intake does not predict weight change among children and adolescents. *Int J Obes Relat Metab Disord* **28**, 1210–1216.
6. Hunschede S, El Khoury D, Antoine-Jonville S, *et al.* (2014) Acute changes in substrate oxidation do not affect short-term food intake in healthy boys and men. *Appl Physiol Nutr Metab* **40**, 168–177.
7. Moore MS, Dodd CJ, Welsman JR, *et al.* (2004) Short-term appetite and energy intake following imposed exercise in 9- to 10-year-old girls. *Appetite* **43**, 127–134.
8. Bellissimo N, Thomas SG, Goode RC, *et al.* (2007) Effect of short-duration physical activity and ventilation threshold on subjective appetite and short-term energy intake in boys. *Appetite* **49**, 644–651.
9. Bozinovski NC, Bellissimo N, Thomas SG, *et al.* (2009) The effect of duration of exercise at the ventilation threshold on subjective appetite and short-term food intake in 9 to 14 year old boys and girls. *Int J Behav Nutr Phys Act* **6**, 66.
10. Dodd CJ, Welsman JR & Armstrong N (2008) Energy intake and appetite following exercise in lean and overweight girls. *Appetite* **51**, 482–488.
11. Tamam S, Bellissimo N, Patel BP, *et al.* (2012) Overweight and obese boys reduce food intake in response to a glucose drink but fail to increase intake in response to exercise of short duration. *Appl Physiol Nutr Metab* **37**, 520–529.
12. Rumbold PLS, St Clair Gibson A, Allsop S, *et al.* (2011) Energy intake and appetite following netball exercise over 5 days in trained 13-15 year old girls. *Appetite* **56**, 621–628.
13. Nemet D, Arieli R, Meckel Y, *et al.* (2010) Immediate post-exercise energy intake and macronutrient preferences in normal weight and overweight pre-pubertal children. *Int J Pediatr Obes* **5**, 221–229.
14. van Strien T & Oosterveld P (2008) The children's DEBQ for assessment of restrained, emotional, and external eating in 7- to 12-year-old children. *Int J Eat Disord* **41**, 72–81.
15. Mirwald RL, Baxter-Jones ADG, Bailey DA, *et al.* (2002) An assessment of maturity from anthropometric measurements. *Med Sci Sports Exerc* **34**, 689–694.
16. Peronnet F & Massicotte D (1991) Table of nonprotein respiratory quotient: an update. *Can J Sport Sci.* **16**, 23–29.
17. Yelling M, Lamb KL & Swaine IL (2002) Validity of a pictorial perceived exertion scale for effort estimation and effort production during stepping exercise in adolescent children. *Eur Phys Educ Rev* **8**, 157–175.
18. Schneider DA, Phillips SE & Stoffolano S (1993) The simplified V-slope method of detecting the gas exchange threshold. *Med Sci Sports Exerc* **25**, 1180–1184.
19. Hughes AA & Kendall PC (2009) Psychometric properties of the Positive and Negative Affect Scale for Children (PANAS-C) in children with anxiety disorders. *Child Psychiatry Hum Dev* **40**, 343–352.
20. Department of Health (1991) *Dietary Reference Values for Food Energy and Nutrients for the United Kingdom: Report of the Panel on dietary Reference Values, Report on Health and Social Subjects* no. 41. London: HMSO.
21. Muthayya S, Thomas T, Srinivasan K, *et al.* (2007) Consumption of a mid-morning snack improves memory but not attention in school children. *Physiol Behav* **90**, 142–150.
22. Flood JE, Roe LS & Rolls BJ (2006) The effect of increased beverage portion size on energy intake at a meal. *J Am Diet Assoc* **106**, 1984–1990; discussion 1990–1991.
23. DellaValle DM, Roe LS & Rolls BJ (2005) Does the consumption of caloric and non-caloric beverages with a meal affect energy intake? *Appetite* **44**, 187–193.
24. Thompson D, Wolfe L & Eikelboom R (1988) Acute effects of exercise intensity on appetite in young men. *Med Sci Sports Exerc* **20**, 222–227.
25. Pomerleau M, Imbeault P, Parker T, *et al.* (2004) Effects of exercise intensity on food intake and appetite in women. *Am J Clin Nutr* **80**, 1230–1236.
26. King NA & Blundell JE (1995) High-fat foods overcome the energy expenditure induced by high-intensity cycling or running. *Eur J Clin Nutr* **49**, 114–123.
27. King NA, Snell L, Smith RD, *et al.* (1996) Effects of short-term exercise on appetite responses in unrestrained females. *Eur J Clin Nutr* **50**, 663–667.
28. Finlayson G, Bryant E, Blundell JE, *et al.* (2009) Acute compensatory eating following exercise is associated with implicit hedonic wanting for food. *Physiol Behav* **97**, 62–67.
29. Unick JL, Otto AD, Goodpaster BH, *et al.* (2010) Acute effect of walking on energy intake in overweight/obese women. *Appetite* **55**, 413–419.
30. Buchanan CM, Eccles JS & Becker JB (1992) Are adolescents the victims of raging hormones: evidence for activational effects of hormones on moods and behavior at adolescence. *Psychol Bull* **111**, 62–107.
31. Yeomans MR, Blundell JE & Leshem M (2004) Palatability: response to nutritional need or need-free stimulation of appetite? *Br J Nutr* **92**, S3–S14.
32. Westerterp-Plantenga MS, Nieuwenhuizen A, Tomé D, *et al.* (2009) Dietary protein, weight loss, and weight maintenance. *Annu Rev Nutr* **29**, 21–41.
33. Veldhorst M, Smeets A, Soenen S, *et al.* (2008) Protein-induced satiety: effects and mechanisms of different proteins. *Physiol Behav* **94**, 300–307.