Abstract

Current physical activity recommendations are being met by less than 21% of children between 5-15 y. Recent Government initiatives are aiming to increase children’s participation in exercise. However, the effects on an imposed bout of exercise-induced energy expenditure (EE) on energy intake (EI) and appetite (hunger, fullness and prospective consumption) in normal weight children have received a limited research focus to date. Therefore, this thesis aimed to investigate how an imposed bout of exercise-induced energy expenditure (EE) on energy intake (EI) and appetite in normal weight children

The first study investigated whether 17 habitually active girls were able to accurately increase their EI to match the EE following 60 min moderate intensity walking exercise. On average 17% of the EE was compensated for by an increase in EI. However, the ranged for EI change was -160% to +166% indicating large individual responses.

The second study investigated whether 30 min of maximal sprint intermittent sprint cycling exercise would significantly alter EI or appetite in 13 boys and 13 girls. In the boys, hunger and prospective consumption were suppressed whilst fullness increased immediately following the exercise, whilst EI was significantly increased in response to the exercise condition. No significant changes to appetite or EI were observed in the girls.

The third study investigated whether a mid-morning snack, moderate intensity cycling exercise (energy matched to snack) or both would alter EI or appetite in 20 boys and 18 girls. Irrespective of sex, hunger and prospective consumption
were suppressed whilst fullness increased following the mid-morning snack, however this change in appetite did not alter EI as no significant differences were found between conditions.

The fourth study investigated whether 99 recreational sports players (males/females, adults/children) were able to conceptualise their EE following 1 h habitual training into quantifiable amounts of food (chocolate) or drink (sports drink). Only 36 % of the EE from the exercise was met by the estimated amounts of food or drink. Age, sex nor sports participation significantly altered the participants’ accuracy of estimation.

The fifth study investigated whether sex or dietary restraint impacted brain activation responses to visual food stimuli in 15 boys and 14 girls between a fed and fasted condition. Significant differences in brain activation were found between conditions, sexes and dietary restraint, potentially suggesting the differences observed in the previous experimental studies could be attributed to neurological alterations between participants.

In conclusion, the findings presented demonstrate the changes in EI between young adolescents in response to an imposed bout of exercise are extremely variable. Whilst eating behaviours failed to correspond to the EI differences observed between participants, potentially brain activation differences may be responsible. The sex of the participant is more likely to impact EI and appetite following maximal sprint intensity exercise, more so than a bout of moderate intensity exercise. Future research should focus on determining what underpins the variable change in EI between participants following a bout of exercise.
Acknowledgements

My sincerest thanks to my supervisors Professor Craig Williams and Dr. Melanie Moore for their invaluable support, guidance and encouragement throughout my research. Without which, I fear the end would never have been reached!

I would like to thank Dr. Jon Fulford for his assistance throughout all the MRI work accomplished within this thesis. Also for his friendship, which has ‘allowed’ me to vent my frustrations on (too) many occasions!

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To my friends and family who have faithfully supported and encouraged me throughout my studies. In answer to, ‘are you nearly finished yet’ I can now say with much more conviction ‘yes I nearly am’! Thank you for always being there.

Finally to my husband, for putting up with everything and anything remotely and not remotely associated with completing my PhD. Your unquestioning love, belief and devotion has maintained my motivation throughout. I could not have done it without you and will always be eternally grateful. Thank you.
Contribution to the practical work

Study One
This study was designed by a previous postgraduate student (JM) and CW and MM. JM had previously conducted the data collection within sedentary girls and JV collected the data from active girls. Only the work performed by JV was reported within this thesis. Data was collected by JV with assistance from CL and OT. JV wrote the study report and CW and MM edited and revised the study report.

Study Two
This study was based on the overall design of study one, however the exercise intensity was manipulated. This manipulation was a concept from JV and the design of the sprint to rest ratio was a collaboration from CW, MM and JV. Data was collected by JV with assistance from SF. JV wrote the study report and CW and MM edited and revised the study report.

Study Three
This study was based on the overall design of study one and two, however it was an idea by JV to manipulate both sides of the energy balance equation. Data was collected by JV with assistance from SC. JV wrote the study report and CW and MM edited and revised the study report.

Study Four
This study was designed by JV, RE and CW. Data was collected by JV and RE. JV wrote the study report and CW and MM edited and revised the study report.
Study Five

Using fMRI as a measure for assessing brain activations was suggested following additional pilot work using fMRI conducted for Kelloggs by JF, CW and JV. Both JF and JV designed the study. JF created the functional image procedure required to collect the data. JV and JF collected and analysed the data. JV wrote the study report and JF, CW and MM edited and revised the study report.

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<th>Abbreviation</th>
<th>Definition</th>
</tr>
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<tbody>
<tr>
<td>ANOVA</td>
<td>Analysis of Variance</td>
</tr>
<tr>
<td>AREE</td>
<td>Activity Related Energy Expenditure</td>
</tr>
<tr>
<td>BMI</td>
<td>Body Mass Index</td>
</tr>
<tr>
<td>CON</td>
<td>Control Condition</td>
</tr>
<tr>
<td>DEBQ</td>
<td>Dutch Eating Behaviour Questionnaire</td>
</tr>
<tr>
<td>DEBQ-C</td>
<td>Dutch Eating Behaviour Questionnaire for Children</td>
</tr>
<tr>
<td>DLW</td>
<td>Doubly Labelled Water</td>
</tr>
<tr>
<td>DPM</td>
<td>Digital Photography Method</td>
</tr>
<tr>
<td>DTE</td>
<td>Desire To Eat</td>
</tr>
<tr>
<td>EE</td>
<td>Energy Expenditure</td>
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</tr>
<tr>
<td>GET</td>
<td>Gaseous Exchange Threshold</td>
</tr>
<tr>
<td>HD</td>
<td>High-disinhibition</td>
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<tr>
<td>HIE</td>
<td>High Intensity Exercise</td>
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<td>HIIE</td>
<td>High Intensity Interval Exercise</td>
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<tr>
<td>MSIE</td>
<td>Maximal Sprint Interval Exercise</td>
</tr>
<tr>
<td>PA</td>
<td>Physical Activity</td>
</tr>
<tr>
<td>PC</td>
<td>Prospective Consumption</td>
</tr>
<tr>
<td>PET</td>
<td>Positron Emission Tomography</td>
</tr>
<tr>
<td>PHV</td>
<td>Peak Height Velocity</td>
</tr>
<tr>
<td>SD</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td>SE</td>
<td>Standard Error</td>
</tr>
<tr>
<td>SED</td>
<td>Sedentary Condition</td>
</tr>
<tr>
<td>SK</td>
<td>Snack Condition</td>
</tr>
<tr>
<td>VAS</td>
<td>Visual Analogue Scale</td>
</tr>
<tr>
<td>$\dot{V}CO_2$</td>
<td>Volume of expired carbon dioxide</td>
</tr>
<tr>
<td>$\dot{V}O_2$</td>
<td>Volume of oxygen uptake</td>
</tr>
<tr>
<td>$\dot{V}O_{2\text{peak}}$</td>
<td>Peak Oxygen Uptake</td>
</tr>
<tr>
<td>$\dot{V}O_{2\text{max}}$</td>
<td>Maximal Oxygen Uptake</td>
</tr>
<tr>
<td>VT</td>
<td>Ventilatory Threshold</td>
</tr>
</tbody>
</table>
1 Introduction

Maintaining normal body weight\(^1\) is vital to sustain good health, prevent disease and prolong life. Data from the Health Survey for England (HSE, 2012) indicated that the prevalence of overweight and obese children aged 11-15 years was 34.0 % for boys and 36.7 % for girls. This most recent HSE data suggests that the previous year on year rise for the prevalence of childhood obesity appears to be flattening out. Whilst a levelling off in this prevalence is encouraging, further efforts need to be made to elicit a decline.

It is widely accepted that the steady rise in obesity, particularly in the western world, is a result of low levels of physical activity (PA) and excessive consumption of energy-dense, often highly palatable foods and drinks (WHO, 2003; Flegal, Carroll, Kit, & Ogden, 2012; Ogden, Carroll, Kit, & Flegal, 2012; Martins, Morgan, & Truby, 2008; Rennie & Jebb, 2005; Raynor & Epstein, 2001). Both of these, either individually or together, will increase the risk of a positive energy balance. Energy balance is the state in which an individual’s energy expenditure (EE) equals their metabolised energy intake (EI) so that body weight remains constant. Negative energy balance occurs when EE is greater than EI resulting in the loss of body weight whilst positive energy balance occurs when EI is greater than EE and body weight is gained. Just over 1/3\(^{rd}\) of children must have sustained a period of positive energy balance for a prolonged period of time, resulting in undesirable weight gain based on the

\(^1\) Body mass is, irrespective of gravity, expressed in kilogrammes (kg), whereas body weight is an expression of body mass times gravity and is expressed in newtons (N). Despite the distinction and in keeping with consistency of nutritional reports reference to body weight will be expressed as kilogrammes.
current prevalence for overweight and obese children (HSE, 2012). Controlling and/or maintaining energy balance is therefore a key strategy to prevent undesirable weight gain. However, it should be noted that children do need to maintain a slight (1 %) positive energy balance throughout their childhood and adolescence to sustain growth (SACN, 2011).

Targeting the EE side of the energy balance equation by increasing physical activity has been one method used by the UK government to not only prevent weight gain, but also promote health. Current UK recommendations are 60 min of moderate intensity activity every day for children aged 5-18 years (Department of Health, 2011). Statistics for 2012 indicated that only 21 % of boys aged 5-15 years and 16 % of girls aged 5-15 years were meeting their PA targets. More specifically to this thesis, only 14 % of boys and 8 % of girls aged 13-15 year old were meeting their PA targets. The Department for Culture, Media and Sport in partnership with the Department for Education have therefore recently published a policy entitled ‘Getting more people playing sport’ (Jan 2014) to help increase PA participation. Their aim is to increase sports participation primarily in children, but also in young people once they have left school. With initiatives aiming to increase children and young people’s PA participation and overall daily EE, it is therefore important to understand the implications of any food behaviour (EI) changes as a result of these encouraged increases in EE.

Unfortunately, humans are more tolerant of a positive energy balance than a negative one (Blundell, Stubbs, Hughes, Whybrow, & King, 2003). Biological evolution favours body fatness to ensure reproductive integrity is maintained
should the availability of food be restricted. However, scientific and technological evolution has created an environment in which food availability is plentiful and the EE necessary to acquire the food is minimal (Rosenbaum & Leibel, 2010). Physiological mechanisms defend impositions that promote a negative energy balance (weight loss) (King et al., 2007) and if body weight has been lost, the maintenance required to keep it off is strongly opposed (Rosenbaum & Leibel, 2010). Rosenbaum and Leibel (2010) showed that maintaining reduced body weight is more difficult and less likely to be achieved than actual weight loss, largely attributed to increased skeletal muscle efficiency and a lowered resting metabolic rate. In addition, decreased sympathetic nervous system tone, circulating concentrations of leptin, thyroxine and triiodothyronine and increased parasympathetic nervous system tone combine to favour weight regain (Rosenbaum & Leibel, 2010). Therefore it is likely, following an increase in the EE side of the energy balance equation and the resultant relative energy deficit that changes to EI will follow. Key factors that regulate and influence energy balance are depicted in Figure 1.1.

*This image has been removed by the author of this thesis for copyright reasons.*

Figure 1.1 - Key factors that regulate energy balance, taken from Manore et al. (2014) pp. 1467.

It is apparent that maintaining energy balance is not a simple calculation of numbers. The components of energy balance are interactive (Figure 1.2). An increase in EE may result in a change or compensation of not only EI but also spontaneous PA.
Therefore, the main aim of this thesis was to investigate how an imposed bout of exercise alters acute EI and appetite in children aged 12-13 years old. Firstly, the availability and suitability of various methods to measure these changes and their appropriateness for use within the paediatric population will be discussed. The current findings in the adult and child literature will then be presented, followed by the presentation of the research studies conducted as part of this thesis.
2 Literature Review: Choosing Appropriate Methods

2.1 Measuring Energy Intake and Energy Expenditure

Choosing the most appropriate method to measure EI and EE should be carefully considered. Not only should the methods chosen yield precise measurements, but also when working with the paediatric population, the measures need to be suitable to this group. Typically accurate measures of EI and EE in free-living subjects are unsustainable over long periods of time. Therefore, studies aiming to measure both EI and EE are predominantly acute (1 d to usually no longer than 5 d) and laboratory based. Choosing laboratory-based studies represents the trade-off between internal and external validity and between prioritising accuracy over free-living (Hill, Rogers, & Blundell, 1995, Blundell et al., 2009). Figure 2.1 describes the relationship between laboratory and free-living research (adapted from Blundell et al., 2009). Considerations essential for choosing the most appropriate methods for measuring EI and EE for the use with children will be discussed within this chapter.

<table>
<thead>
<tr>
<th>Free Living</th>
<th>Laboratory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less precision and accuracy</td>
<td>Greater precision and accuracy</td>
</tr>
<tr>
<td>Less control, greater ecological relevance</td>
<td>Greater control, less naturalistic</td>
</tr>
</tbody>
</table>

Free living studies Intervention studies Laboratory studies

Figure 2.1. Conceptual description of the relationship between laboratory and free-living research (adapted from Blundell et al., 2009)
2.1.1 Measurements of energy intake

Energy intake is a measure of the total amount of energy contained within foods and drinks consumed orally over a period of time. The main purpose of measuring EI is to establish quantitative information on the amount of energy and/or nutrients available for metabolism. The technique chosen for estimating EI will of course, largely depend on the nature of the question being asked (Livingstone & Robson, 2000). Understanding dietary habits in the early childhood and adolescent years is important as they track closely into adulthood (Mikkila, Räsänen, Raitakari, Pietinen, & Viikari, 2005) thus providing information about long term energy balance if captured accurately. The first part of this chapter will explore the reliability and validity of both prospective and retrospective methods suitable for measuring EI in the paediatric population.

First however, it is important to understand the gold standard reference method to validate measurements of EI. Basiotis, Welsh, Cronin, Kelsay, and Mertz (1987) suggested that a ‘precise’ estimate of EI would be defined as, “an X-day average intake being within 10 % of the “true average” intake for the individual or the group 95 % of the time” (pp 1638). Based on the principle of energy metabolism where EI = EE in a weight stable free-living population, validation of EI methods are via direct comparison to total EE. The gold standard method for measuring EE is via the doubly labelled water (DLW) method, which provides an independent and unbiased measure of EE typically over a period of 7 to 14 d (see chapter 2.1.2.1.1 for the mechanism behind this method). Accurately measuring EE through DLW calculations can verify the validity and accuracy of reported total EI, as they should match if the participant is weight-stable. However using EE as a reference for EI is not perfect as reviewed by
Livingstone and Black (2003) the accuracy of the EI:EE ratio even under the best conditions still yields a mean underreporting intake bias of 3%.

2.1.1.1 Prospective measures

Prospective measures assess current EI, however they are labour intensive for either/both the participant and researcher involved.

2.1.1.1.1 Duplicate diet

With the duplicate diet, subjects are required to weigh out two portions of everything they eat. One portion is eaten, the other is put to one side to be chemically analysed for energy and nutrient content. Errors associated with food composition tables are negated by this method. This method is chosen predominantly with energy balance studies in free-living populations as opposed to laboratory-based studies. Free-living studies aim for the participants to be able to carry out their habitual lifestyles without strong influences by the researchers or study requirements. Disadvantages to the duplicate diet method include the expense to supervise and analyse the collected food. Secondly, participants may collect less food than the amount that was actually consumed so not to ‘waste’ food, especially expensive products such as meat (Nelson, 2000). Participants may change their dietary habits to make collection easier, for example: portions allocated may be smaller to compensate for the portion put to one side or an increase in pre-packaged food maybe chosen (Nelson, 2000). Therefore, the benefits obtained from such a precise measure can be offset against participants changing their habits for the purpose of physically collecting their intake. Ultimately, this method is costly and would require proxy support for use within paediatrics, particularly for younger children. Consequently, it is usually only utilised for research within the paediatric population for investigations of specific vitamin or mineral contents in the diet.
and also where a semi-controlled setup such as a school or academy is available (Shimbo, Watanabe, Nakatsuka, Yaginuma-Sakurai, & Ikeda, 2013; Lu, Schenck, Pearson, & Wong, 2010).

2.1.1.1.2 Metabolic kitchen

Food is provided to participants by the researcher primarily within a laboratory setting. This can be either as a pre weighed meal with restricted choice for portion size and/or food items or as a range of food items offered in excess of normal intake for the participant to choose from (buffet style). For both methods, plate weight for all food items offered are recorded both pre and post consumption to calculate intake. Food items offered should have invariable compositions ensuring actual nutrient intake can be calculated. This method however does not reflect free-living food choices; neither can it be sustained for large subject numbers over a long study period, as it is costly and time consuming. However, there are no age-restricted concerns when using this method with children.

2.1.1.1.3 Food records

Food records from weighing intake are the most widely used technique within studies measuring EI, a method first described by Widdowson (1936). Using portable scales (most commonly digital scales nowadays), participants are asked to weigh everything immediately before consumption and weigh anything that is left over and record this information in a food diary. This method can provide accurate measurements of portion sizes over a flexible duration of recording time (usually between 3 and 7 d to include at least 1 weekend day). However, subject bias is common with participants underreporting or reducing/changing their intake to simplify the recording process. For example, Champagne, Baker, DeLany, Harsha, and Bray (1998) found that 118 children
aged 10 y recording their intake over 8 d, underreported their intake by 17-33 % when compared to EE measured by DLW. Similarly Livingstone et al. (1992) found EI measured over 7 d in children aged 12 and 15 y matched 89 ± 12 % and 78 ± 18 % respectively of total EE.

The food records method is also unsustainable for long periods as participants find the recording process laborious. However, only collecting food records over a short period of time may hinder the capture of any seasonal variations to the diet and also some micronutrients, which may need up to 50 d of recording (Collins, Watson, & Burrows, 2010). This is because some micronutrients, for example omega 3 fatty acids, occur in a limited number of foods that may be missed if only a 3 or 7 d recording period is used. Emmett (2009) therefore, suggested using food frequency questionnaires in conjunction with food records to assist in the capture of regular but infrequent food groups.

A more simplified version of the food records method is to ask the participant to record portion sizes of food intake using household measures such as a cup, bowl, teaspoonful etc. with the use of aids such as food models or photos. These aids can improve estimates of portion sizes (Nelson et al., 1997). Using household measures is less time consuming for the participant and will not require pre-existing familiarity with weighing scales, however portion size accuracy is compromised. Distortions to habitual diet are also less common with this method (Nelson, 2000) due to the simplified recording method. Livingstone and Robson (2000) concluded that under-reporting using food records in adolescents and younger adults was approximately 20 %, irrespective of the direct weighing or household measures method.
2.1.1.1.4 Digital photography

A novel method for assessing EI is the digital photography method (DPM), made feasible with the advances in modern technology, primarily mobile telephones that include a digital camera. This method has the potential to ameliorate some of the user burden associated with the food records method. Participants take a photograph of their meal alongside a fiducial marker, which acts as a point of reference when calculating portion size. Time stamps attached to each image can also add valuable information for the researcher and requires no additional input from the participant. A validation study by Sabinsky, Toft, Andersen, and Tetens (2013) looking at children’s school lunch sandwiches found the correlation coefficients between DPM and weighed food intake to range from 0.89 to 0.97. Further analysis indicated the mean difference of the meal index of dietary quality score between the two methods was 0.07, and the 95% limits of agreement were ± 2.33 around the bias. These findings indicated that there were no clear significant differences between DPM and weighed food intakes for measures of children’s school lunch. Daugherty et al. (2012) found that adolescents (11-18 y) were more efficient at using DPM for food records than adults (21-65 y); suggesting DPM to be a viable method for use with adolescents. DPM is still in its infancy, however there is no doubt that this method will dominate as a method of assessing EI as technology continues to evolve.

2.1.1.2 Retrospective measures

Retrospective measures require the subjects to recall their intake over a specific period of time. These are commonly less expensive and quicker to administer than prospective measures. Common issues with children include cognitive
ability to recall their intake and comprehension of the questions asked (Collins et al., 2010).

2.1.1.2.1 24-h recall

Wiehl first described the 24-h recall method in 1942 (Wiehl, 1942). This method has since been updated and is presently conducted as follows: a trained investigator asks systematic open-ended questions to a subject enabling a detailed recall of intake over the previous 24 h. This is a quick method, usually taking between 10-15 minutes to complete, therefore maintaining subject motivation and compliance. One measure of 24 h intake however, will not be sufficient to classify habitual intake due to day-to-day variation of the diet (Livingstone and Robson, 2000). Tarasuk and Beaton (1992) investigated day-to-day variation within the diet and concluded from 29 individuals who reported their intake for a year, that the coefficient of variance for both macro and micronutrients ranged from 19.6 % (carbohydrate) to 102 % (Vitamin A) and total EI 27.2 %. The 24-h recall method is appropriate if a snapshot of EI from a large cohort is required. Repeated 24-h recalls are more valid for habitual diet. Errors with portion size (as household measures are commonly described with this method) may also impact accuracy. Further improvements for the validity of portion sizing have been found when visual aids (props or photos) are used with adults, although it was suggested that the use of visual aids in children might increase confusion (Robson and Livingstone, 2000). Issues with cognitive ability and comprehension for younger children can limit this method's validity for use within the younger paediatric population (Collins et al., 2010); see chapter 2.1.1.3.1 for discussion on age appropriateness for measuring EI.
2.1.1.2.2 Diet history

The diet history method, as with 24-h recall, requires a trained investigator to collect the diet history through an interview format that can last up to 2 h. A 24-h recall is collected first before more detailed information about typical ranges of foods, frequencies and amount of food likely consumed for each mealtime is recorded. Differences between seasons, as well as weekday and weekends are clarified. The accuracy of the diet information collected can vary depending on the skill of the interviewer. Care should be given to avoid participants over-reporting foods perceived to be healthy; similarly underreporting of unhealthy foods. This method can be too complex for younger children to comprehend (Collins et al., 2010).

2.1.1.2.3 Food frequency questionnaire

Food frequency questionnaires are self-administered reports where participants are asked to indicate typical consumption of a food type over a period of time, usually within the last year. An example excerpt of a food frequency questionnaire is shown in Table 2.1.

<table>
<thead>
<tr>
<th>Table 2.1 - Example of a food frequency questionnaire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chips</td>
</tr>
<tr>
<td>Potatoes (boiled, baked, mashed)</td>
</tr>
<tr>
<td>Sweet potato, squash, swede</td>
</tr>
<tr>
<td>Carrots (fresh, tinned, frozen)</td>
</tr>
</tbody>
</table>
Food frequency questionnaires are very suitable for large epidemiological studies where questionnaires can be posted to subjects. The number of food items included can vary from as little as 9 items (if looking to assess a specific nutrient e.g. calcium), or as many as 300 items (for a more detailed overview of the diet) (Nelson, 2000). Although this method is quick to administer, it can be time-consuming in development and validation of the questions depending on the desired outcome. Ensuring the questions are worded appropriately, particularly when referring to food groups rather than individual foods is important to negate any confusion. This method also lacks detail for exact intakes; rather it provides an overview of the diet. It has been suggested that food frequency questionnaires are not appropriate for children under 9 y due to the complex comprehension required for it to be completed accurately (Collins et al., 2010).

2.1.1.3 Factors affecting energy intake measures

2.1.1.3.1 Age

When the target population for collecting EI data is children and adolescents, taking into consideration their age is important to ascertain reliable data. Collecting data from children under 8 y will usually rely heavily on proxy reports primarily from parents (Livingstone & Robson, 2000). Children under 8 y have limited literacy skills, are unable to conceptualise frequency and portion size of food and most often it is the adult who is controlling the eating environment (Collins et al., 2010). Working parents however, are less able to accurately report their children’s intake during the periods of absence from their child (Baranowski, Sprague, Baranowski, & Harrison, 1991); a potential limiting factor with the rise in working parents (Office for National Statistics, 2013). Children aged approximately 12 y and over are more likely to be capable of
independently reporting their dietary intake, although this will vary depending on the assessment method used (Livingstone, Robson, & Wallace, 2004). However, adolescents over 12 y are commonly less willing, interested, and co-operative compared to younger children and are more likely to find the tasks inconvenient, irritating and tedious resulting in poor compliance and increased reporting error (Collins et al., 2010). Burrows, Martin, and Collins (2010) summarised that between 8 and 12 y, there is a transition period where a child becomes more accurate at reporting their own dietary intake and still interested enough to perform the task accurately. Generally children over 9 y can be considered capable of accurately reporting their EI, however cognitive variation will persist and should be taken into consideration when recruiting children of this age. Recommendations however, have not been made as to who (child or adult) should report EI for children between 8 and 12 y (Collins et al., 2010). It is therefore important when collecting EI in the paediatric population that the age of the target group is considered to ensure the most appropriate EI recording method is chosen. Livingstone and Robson (2000) have summarised the respondent and observer considerations between collecting EI data in children and adolescents, Table 2.2.
Table 2.2 - Respondent-observer issues in EI assessment of children and adolescence. Adapted from Livingstone and Robson (2000).

<table>
<thead>
<tr>
<th></th>
<th>Childhood</th>
<th>Adolescence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognitive Abilities</td>
<td>Low literacy skills</td>
<td>Full cognitive capability</td>
</tr>
<tr>
<td></td>
<td>Limited attention span</td>
<td>Extensive knowledge of food</td>
</tr>
<tr>
<td></td>
<td>Limited concept of time</td>
<td>Questionable knowledge of food preparation</td>
</tr>
<tr>
<td></td>
<td>Limited memory</td>
<td>Limited memory</td>
</tr>
<tr>
<td></td>
<td>Limited knowledge of food, portion size and food preparation</td>
<td>Questionable knowledge of food preparation</td>
</tr>
<tr>
<td></td>
<td>Dietary reporting by surrogate respondents</td>
<td>Onus of reporting on self</td>
</tr>
<tr>
<td>Dietary Habits</td>
<td>Rapidly-changing food habits, but (more) structured eating patterns</td>
<td>Rapidly-changing food habits, but unstructured eating patterns</td>
</tr>
<tr>
<td></td>
<td>More in-home eating</td>
<td>More out-of-home eating</td>
</tr>
<tr>
<td></td>
<td>Under supervision of adults</td>
<td>Less supervised by adults</td>
</tr>
<tr>
<td></td>
<td>Parental influence important</td>
<td>Peer influence important</td>
</tr>
<tr>
<td>Psychological</td>
<td>Food satisfies hunger</td>
<td>Food is a means of self-expression</td>
</tr>
</tbody>
</table>

2.1.1.3.2 Under or over reporting

Under reporting is a common error within all free-living EI recording methods. Rennie, Coward, and Jebb (2007) established using data from 1551 adults, that 75 % of males and 77 % of females could be classified as under-reporters. A review of 19 adult studies by Trabulsi and Schoeller (2001) showed self-reported dietary EI when validated against DLW was under reported in all bar one study where the participants over reported by 24 %. The average under reporting for all 19 studies was 2.31 MJ/d with the range of underreporting from 7.08 MJ/d to over reporting by 2 MJ/d. A similar review by Livingstone and Robson (2000) in children also comparing self-reported dietary intake against
DLW, found 7 incidences of a mean over reporting and 14 incidences of a mean under report for EI. The range was from -6.08 MJ to +3.92 MJ and the average of all 21 cases reported was an under report of EI by 0.57 MJ. Steps should be taken to minimise the probability of underreporting as much as possible by limiting the user burden wherever achievable. Examples would be to reduce the number of days intake is recorded over and to have detailed recording sheets making it easy for the participant to input their intake accurately. A reduced number of recording days would however compromise how representative the diet would be of habitual intake.

Livingstone and Robson (2000) reported that there was a trend for under-reporting to increase as a child ages. They suggested this could be due to a number of reasons including:

- Younger children will have help from adults completing their food records; for adolescents, the responsibility is more likely to fall on to them.
- Adolescents have increased free access to foods; younger children are in a more controlled and supervised food environment.
- Novelty and curiosity of younger children to keep track of their food increases compliance; adolescents may find the task boring and laborious.
- Adolescents have an increased awareness and concern for body shape/image that may result in inhibited eating and/or recording.

2.1.1.3.3 Weight status

Obese adolescents and children significantly under-report EI compared to their non-obese peers (Livingstone & Robson, 2000). The magnitude of under reporting in obese children is also age related with adolescents underreporting up to 40 % (Bandini, Schoeller, Cyr, & Dietz, 1990) compared to up to 25 % in 10 y olds (Champagne et al., 1998). Why obese children are more likely to
underreport remains unclear; however reasons are likely to match those found with adults, such as body dissatisfaction (Scaglius et al., 2009), embarrassment to record all foods consumed, hassle of recording, social pressure of what ‘society’ defines as appropriate dietary behaviour, and subconscious memory lapse (Macdiarmid & Blundell, 1998). Coupled with adolescents’ heightened preoccupation of body image, it could be suggested that obese adolescents also feel more stigmatised than obese adults regarding their weight status (Livingstone & Robson, 2000) and therefore misrepresent their true dietary intake when asked to keep a record.

2.1.1.3.4 Using nutritional databases

All methods mentioned above except for the duplicate diet and the metabolic kitchen will require the use of a nutritional database for analysis such as CompEat (Nutrition Systems, Oxon, England), WinDiets (WinDiets Research, Robert Gordon University, Aberdeen, UK), NutriCalc (NutriCalc Ltd, Devon, England) or Nutritionist Pro (Axxya Systems, Redmond, WA, USA). Limitations associated with using nutritional databases include: how up to date the database is and the accuracy between the composition of the foods within the tables and composition of the food consumed. Other limitations will also depend on the descriptive detail reported by the participant, for example if a ‘ham sandwich’ is recorded, the difference between a thickly sliced brown seeded bread sandwich with low fat spread and cold roast ham to a thinly sliced white bread sandwich, with butter and processed ham will be great and will ultimately result in inaccurate reporting of EI and macronutrient composition data. Ensuring descriptive detail is recorded alongside food records or retrospective recordings are paramount to achieve accuracy within these methods.
2.1.1.4 Summary

Reviews by Livingstone et al. (2004) and McPherson, Hoelscher, Alexander, Scanlon, and Serdula (2000) were both unable to conclude on a ‘best practice’ for measuring dietary intake in the paediatric population. A summary of methods measuring EI and common errors are shown in Figure 2.2 taken from Rutishauser (2005). Ultimately the method chosen will depend on the research question asked and the resources available. Methods to measure EI used within the studies presented in this thesis are summarised in Table 2.3 along with a summary of the pros and cons of all methods previously discussed.

This image has been removed by the author of this thesis for copyright reasons.

Figure 2.2 - A summary of methods available to measure energy intake and common errors to these methods, taken from Rutishauser (2005) pp. 1103.
Table 2.3 - Pros and Cons of methods for measuring energy intake and whether these methods have been used within the studies presented in this thesis.

<table>
<thead>
<tr>
<th>Method</th>
<th>Pros</th>
<th>Cons</th>
<th>Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duplicate Diet</td>
<td>Accurate nutrient intake, not subject to error associated with food composition data, objective measure</td>
<td>Expense of wasted food and laboratory analysis, high user burden, requires highly motivated and literate participants, not suitable for large scale, unlikely to capture habitual intake, wasteful</td>
<td>Chapter 4, 5, 6 + 8</td>
</tr>
<tr>
<td>Metabolic Kitchen</td>
<td>Accurate nutrient intake, not subject to error associated with food composition data, low respondent burden</td>
<td>Expensive, not representative of free living choice</td>
<td></td>
</tr>
<tr>
<td>Food Records</td>
<td>Can provide accurate intake details, portion size recorded in real time, can be photographed to aid interpretation, habitual intake recorded</td>
<td>High respondent burden, requires literacy and motivation of respondent, timely and costly to interpret data, error associated with food composition tables, requires several days of recordings</td>
<td></td>
</tr>
<tr>
<td>24 h Recall</td>
<td>Low respondent burden, food intake patterns are not altered, participant literacy not required, quick to administer</td>
<td>Not representative of habitual intake, recall bias and ability, expensive to administer to large numbers, timely to analyse</td>
<td>Chapter 4 + 5</td>
</tr>
<tr>
<td>Diet History</td>
<td>Participant literacy nor required, details of individual foods consumed available</td>
<td>Requires skilled investigators with knowledge of local foods, investigator bias, timely (60-90 min), recall bias, estimates of portion size can be difficult, expensive</td>
<td></td>
</tr>
<tr>
<td>Food Frequency</td>
<td>Low respondent burden, assesses habitual intake over extended periods of time, can be self-administered, inexpensive, can be nutrient or food group focused, analysed quickly</td>
<td>Results limited to foods contained within the list, recall bias, requires literacy skills if self administered, timely to develop, needs to be population specific, poor estimation of portion sizes</td>
<td></td>
</tr>
</tbody>
</table>
2.1.2 Measurements of energy expenditure

Energy expenditure is a measure of the total amount of energy utilised from performing activities whether at rest or physically active. Often, the purpose of measuring EE is to establish the energy costs of PA. The method chosen for measuring or estimating EE will largely depend on the nature of the question being asked. There are two main groups of assessment methods:

Objective – results are obtained from calculations based on a physiological or biomechanical parameter for example, heart rate, movement, or breath analysis. Whilst objective measures are not subjective, user error is common.

Subjective – results are obtained from questionnaires, interviews, diaries and observations. Subjective measures are open to interpretation and therefore may be influenced by the investigator or participant.

This section will explore the reliability and validity of various EE recording methods suitable for use in paediatrics. It should be noted however, that accurate measurements of PA in children is often challenging due to their intermittent and sporadic movements (Kohl, Fulton, & Caspersen, 2000).

2.1.2.1 Methods for measuring energy expenditure

2.1.2.1.1 Doubly labelled water

Doubly labelled water is considered the gold standard method for measuring EE in free-living subjects (Schoeller & van Santen, 1982). This method was first developed by Lifson, Gordon, and Mcclintock (1955) however, many refinements to the methods have since been employed. In 1983 Schoeller was the first to use DLW in humans when the cost of the isotope decreased, making
DLW a viable yet still expensive measurement for research. Currently the method involves the participants consuming a bolus of two stable isotopes $^2\text{H}_2\text{O}$ and $\text{H}_2^{18}\text{O}$, which are used as tracers (these are naturally occurring isotopes which are non-radioactive and safe to use with children) (Medical Research Council (MRC), 2014). The heavier atoms ($^2\text{H}$ and $^{18}\text{O}$) can be measured in bodily fluids, usually blood, urine or saliva. The $^2\text{H}$ is lost only as water whereas the $^{18}\text{O}$ is lost through water and expired air ($\text{C}^{18}\text{O}_2$); the difference between the two tracer excretion rates represents CO$_2$ production rate (McArdle, Katch, & Katch, 2010). Using approximate ratios of metabolised fat, carbohydrate and protein, EE can be calculated. These measures based on excretion rates need to be collected over a period of time; usual recording is between 5 and 21 d. Measuring over such a period of time could be a positive or negative aspect of this method depending on the study question. Limitations primarily relate to the expense of the isotopes and equipment required to measure them; in 2002 it was estimated that the cost for the dose and analysis from one individual would be between £600-750 (Ainslie, Reilly, & Westerterp, 2003). A further limitation is the lack of specific information regarding how the energy was expended for example measures of exercise intensity, duration, or exercise frequency are not possible (McArdle et al., 2010).

2.1.2.1.2 Direct calorimetry

There are two methods of measuring EE through direct calorimetry, both based on the principle that all biochemical processes occurring within the body will result in heat production (McArdle et al., 2010). Measuring heat production, similar to measuring heat combustion of foods, results in a measure of the energy expended to produce heat, which is associated with work done. Participants are placed in either a direct calorimetry chamber or a body suit,
where known volumes of water pass through (the chamber or suit). The water absorbs the heat generated by the participant and the change in water temperature measured is directly proportional to the subjects’ EE. This method requires specialist equipment and trained personnel to operate, it is not indicative of free living and only 1 participant can be measured at a time. Therefore, although this is a precise measure the feasibility in the habitual setting and for large study numbers is restricted (McArdle et al., 2010; MRC, 2014). Some children may also not be comfortable remaining in the confined space of the calorimetry chamber by themselves, therefore this is not a popular method for use within the paediatric population.

2.1.2.1.3 Indirect calorimetry

Oxygen is the dependent energy supply for all biochemical reactions. Monitoring oxygen uptake ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) provides accurate measures of metabolic rate. EE can be calculated if the respiratory exchange ratio (RER) is under 1 using the equations by Péronnet and Massicotte (1991).

Fat oxidation: $[\dot{V}O_2 \text{ L min}^{-1} (1.695) - \dot{V}CO_2 \text{ L min}^{-1} (1.701)]$

Carbohydrate oxidation: $[\dot{V}CO_2 \text{ L min}^{-1} (4.585) - \dot{V}O_2 \text{ L min}^{-1} (3.226)]$

EE: $\text{kJ min}^{-1} = (\text{Fat oxidation} \times 39) + (\text{Carbohydrate oxidation} \times 16)$

However if the RER is over 1 (high intensity exercise), the basic principle of indirect calorimetry is confounded. With high intensity exercise, not all the CO$_2$ produced is from the oxidation reaction, as there is a significant contribution from the buffering of hydrogen ions. In this case EE should be calculated using the equation by Weir (1949):

EE: $\text{kcal min}^{-1} = [\dot{V}O_2 \text{ L min}^{-1} (3.94) + \dot{V}CO_2 \text{ L min}^{-1} (1.11)]$
Expired air can be collected and measured for volume and concentration of oxygen and carbon dioxide a number of ways. Methods include:

- **Closed collection systems** – for example Douglas bags. Expired air is collected into an airtight bag for a set duration of time. Volume of expired air, along with the concentration of $O_2$ and $CO_2$ are measured. This method can be prone to user error and maintenance status of the equipment is paramount to maintain accurate measures (McArdle et al., 2010; MRC, 2014).

- **Open-circuit systems** – for example a hood or canopy set up (ventilated open-circuit systems) or into a mouthpiece or mask (expiratory collection open-circuit system). Expired air is measured for $O_2$ and $CO_2$ concentrations along with volume (of each breath) (McArdle et al., 2010; MRC, 2014).

Due to the expense and bulk of the equipment this method is predominantly unsuitable for studies requiring large participant numbers or for free-living measures. Some of these devices have however been made more portable for free living analysis and have shown good reliability. For example, the Cortex MetaMax 3B portable metabolic system, (Cortex Biophysik GmbH, Leipzig, Germany) has been shown to have good reliability (2.0 – 3.6 % typical error) to that of the stationary MetaMax 3B and automated Douglas bag system (Vogler, Rice, & Gore, 2010). However, these portable devices are still bulky and cumbersome and are often are not suitable for measures in small children.

### 2.1.2.1.4 Pedometry/accelerometry

An accelerometer or pedometer is a small device that attaches to the body (usually on a belt around the waist). An accelerometer records the frequency and magnitude of the body’s acceleration during movement in one (longitudinal
axis), two (vertical and medio-lateral) and three (vertical, medio-lateral and anterior-posterior) directions (Chen & Bassett, 2005). Acceleration signals generated from acceleration in the body’s movement are digitised to produce the activity counts. Pedometers, work by a weighted pendulum touching a metal contact that completes the circuit and registers the step. Various equations have been developed to convert these counts into estimated measures of EE. Accelerometer activity counts, particularly when captured in triaxial format, correlate well to EE as indicated by Plasqui, Joosen, Kester, Goris, and Westerterp (2005) who found activity counts per day recorded by the triaxial accelerometer Tracmor (Philips Research, Maastrict, The Netherlands) when in combination with age, height and body mass explained 83 % of the variation of total EE when compared to EE calculated from the DLW technique. Duncan, Schofield, Duncan, and Hinckson (2007) investigated the accuracy of step counts in two makes of pedometer: Yamax Digiwalker SW-200 (Yamax Corp, Tokyo, Japan) and New Lifestyles NL-2000 (New Lifestyles Inc., Lee’s Summit, MO), in children (5-11 y) compared to observation of step counts at 3 different speeds of walking. The loss of precision between the pedometer and the observed step count was calculated by the variance of prediction error divided by the variance of the criterion value. The pedometers correlated well at the faster speeds: at 90 m min\(^{-1}\) the SW-200 reported the loss in precision to be of 7.1 % and the NL-2000 2.7 % and at 66 m min\(^{-1}\) the loss in precision were 35.0 % and 17.5 % respectively. However at the lower walking speed of 42 m min\(^{-1}\) the loss of precision was much greater at 108.8 % and 67.4 % respectively (Duncan et al., 2007). The imprecision of pedometers at low intensity PA was further reviewed by McNamara, Hudson, and Taylor (2010) who suggested that the monitors were not sensitive enough to accurately record slow walking
movement in children. Pedometers are however often favoured in large studies as they are cheaper than triaxial accelerometers.

Common problems surrounding the use of pedometry and accelerometry measures are:

- Only lower body movements are recorded
- Unable to record any water based PA
- Struggles with wear compliance, (particularly with children)

A study of 11-y-old children predicted the number of wear days of an accelerometer required to achieve reliability coefficients based on Spearman-Brown prophecy formula a $r = 0.7$ would need between 2.9 and 3.1 d, a $r = 0.8$ would need between 4.9 and 5.3 d and finally to achieve a $r = 0.9$ between 11 and 11.9 d (Mattocks, Tilling, Ness, & Riddoch, 2008). A further complication in measuring EE by accelerometry or pedometry is which equation to use to estimate EE. Nilsson et al. (2008) reviewed 5 equations used to predict total EE from accelerometer data counts in 1321 9-10 y children and found the standard deviation between the prediction equations was $\pm 1.44$ MJ day$^{-1}$. Although accelerometry or pedometry are feasible methods for use within paediatrics, the limitations associated with these methods need to be carefully considered.

2.1.2.1.5 Heart rate monitoring

Heart rate (HR) monitoring is a cost effective and feasible method for measuring free-living EE in children. Participants are fitted with a HR monitor and a watch that records HR over a period of time. HR has a linear relationship with $O_2$ uptake from which EE can be calculated (when above resting levels). Establishing the HR to $O_2$ uptake relationship needs to be conducted on an individual basis, usually in a laboratory setting, prior to data collection. Strath et
al. (2000) showed good reproducibility within adult subjects; $r = 0.87$, with 75% of the variability in $\dot{V}O_2$ being explained by HR, age and fitness levels. More specifically in children (7-15 y), Livingstone et al. (1992) compared calculations of total EE from HR to DLW and found the 95% confidence limits of agreement (mean difference ± 2 SD) were -1.99 to +1.44 MJ/d. They also showed that total EE discrepancies ranged from -16.7% to +18.8% of DLW total EE estimates. This would indicate that the heart rate method yields similar accuracies in both adult and children.

A more simplified method for measuring EE from HR data that does not require the relationship with oxygen uptake to be pre-established was derived for adults by Keytel et al. (2005) where sex equals 1 for males and 0 for females:

$$ EE = \text{sex} x (-55.0969 + 0.6309 \times \text{HR} + 0.1988 \times \text{body mass} + 0.2017 \times \text{age}) + (1 - \text{sex}) x (-20.4022 + 0.4472 \times \text{HR} - 0.1263 \times \text{body mass} + 0.074 \times \text{age}). $$

However this method reduces some of the accuracy associated with establishing the $\dot{V}O_2$ - HR relationship prior to measurement, which helps to accounts for individual fitness levels. Keytel and colleagues (Keytel et al., 2005) found the estimated EE from the equation correlated well ($r=0.857$) to measured EE. Having an indication of individual fitness will ultimately increase the accuracy of results obtained from the HR method.

Both the $\dot{V}O_2$-HR and HR method are less reliable for very low and very high PA intensities as the relationship between HR and $O_2$ uptake is not linear at these levels (Hills, Mokhtar, & Byrne, 2014). Maintaining wear compliance, as with accelerometer and pedometer data collection in paediatrics, is also a limitation to this method.
It should be noted that using HR and accelerometry in combination have also been utilised as these measure different aspects of EE. Corder, Brage, Wareham, and Ekelund (2005) compared measured EE from indirect calorimetry to estimated EE from activity counts, HR and a combination of activity counts and HR in 39 children 13.2 ± 0.3 y. The combination of activity counts and HR had the strongest correlation to measured EE (r = 0.86) compared to HR (r = 0.82) and activity count (r = 0.69) alone.

2.1.2.1.6 Metabolic equivalent (MET)

Metabolic equivalents (MET) are values that are assigned to PA from which estimations of EE are calculated, typically used with the PA logs and observation methods. One MET is defined as ‘the ratio of work metabolic rate to a standard resting metabolic rate of 1 kcal (4.184 kJ)kg⁻¹h⁻¹’ (pp s498; Ainsworth et al., 1993). A compendium of PA with corresponding MET values was first compiled by Ainsworth et al. (1993). The compendium has since been updated by Ainsworth and colleagues in 2000 (Ainsworth et al., 2000) and again in 2011 (Ainsworth et al., 2011). Byrne, Hills, Hunter, Weinsier, and Schutz (2005) examined the relationship between MET and indirect calorimetry and found in 769 weight stable healthy adults that \( \dot{V}O_2 \) was over-estimated by ~35 % and that EE was over estimated by ~20 %. There are gross inaccuracies in measuring EE from METs, however the compendium was never established to determine actual EE, but instead to simply classify PA within population health research (Hill et al., 2014). An updated compendium for use with children has also been published (Ridley, Ainsworth, & Olds, 2008).
2.1.2.1.7 Observations

In an observational measure of PA, the participant is observed performing their habitual activity providing detailed contextual information. The observer subjectively defines the intensity of the PA to calculate an estimated EE. This is a time consuming method for the researcher/observer who will need to have prior training to ensure accurate capture of PA. However the observation method is commonly used within young children’s research as the stop-start nature of children’s PA can be accurately quantified (Brown et al., 2006). This method can only be used for short periods of observation time, for example school break times, due to the investigator burden of this method. Behavioural and peer cues along with environmental conditions can also be recorded providing increased qualitative information regarding why PA may occur at certain times. Different PA observation tools have been created depending upon the design of the research question. One such tool the ‘System for Observing Children’s Activity and Relationships during Play (SOCARP)’ was validated against mean accelerometer counts in 114 children (Ridgers, Stratton, & McKenzie, 2010) and was found to have a significant correlation \((r = 0.67, P=0.01)\) between the observation tool and mean accelerometer counts. In addition, the SOCARP was found to have acceptable interobserver reliabilities (percentage agreement) for activity level (89 %), group size (88 %), activity type (90%) and interactions (88 %) (Ridgers et al., 2010). The observational method for measuring EE is a method primarily used with young children as opposed to adolescents and adults.

2.1.2.1.8 Physical activity log

Similar to a food diary, in a physical activity log, PA is recorded by the participant over (usually) a 24 h period. The day is typically broken down into 15
min blocks where the participant records their activity performed (sleeping, sitting, walking etc) over that period. Tendencies for over- and underestimations are common, along with high respondent burden, limiting compliance (McArdle et al., 2010). Proxy reports would be required for younger children, consequently this method has primarily been used with adolescents and adults only. Secondly due to the sporadic and intermittent nature of younger children’s PA this method fails to capture with any detail this type of exercise (Hills et al., 2014). The EE value estimated from this method will only be as good as the information recorded (Hills et al., 2014). However, physical activity logs are a cheap and easily administered. Bratteby, Sandhagen, Lötborn, and Samuelson (1997) conducted a validation study with fifty 15 y old adolescents, whereby they compared EE measured from a 7-d activity diary to EE measured from DLW. The mean differences between the two methods for all adolescents was 0.15 MJ/d. Brattenby et al. (1997) concluded that the physical activity log method provided a close estimate of EE within this population group.

2.1.2.1.9 Questionnaires

Similar to the food frequency questionnaire, a self-reporting questionnaire can be administered to determine habitual PA. The design and detail of the questionnaire can vary depending on the desired outcomes. Global self-report questionnaires typically have 1 to 4 items that categorise main levels of activity. Quantitative history questionnaires can be up to 60 items long, aiming to capture domains of PA. Questionnaires are unable to provide accurate values of EE, and provide rather an overview of habitual PA patterns. Some questionnaires are designed to measure only sports participation, whereas others look to quantify subjective intensities of PA. Questionnaires have been specifically modified for use with children (Kowalski, Crocker, & Faulkner,
1997), however proxy reporting may still be required for younger children. Children under 10 y for example have been found too young to accurately self-report their PA (Sallis, 1991). Unfortunately, PA questionnaires do not correlate well to measured EE from DLW and a review of 20 studies in adults showed a range in correlation from $r = 0.05$ to $r = 0.63$ (Neilson, Robson, Friedenreich, & Csizmadi, 2008). More specifically in children, Corder et al. (2009) assessed the validity and reliability of 4 self-reported questionnaires against DLW and accelerometry and found the association between questionnaire and criterion methods varied from $r = 0.09$ to $r = 0.46$. Predominately the questionnaires were able to assess group-level PA EE but there were large errors at the individual level. Using questionnaires can however be useful for ranking the EE of children (Corder & Ekelund, 2008; Corder et al., 2009).

### 2.1.2.2 Summary

Similar to the measurement of EI, the method chosen to measure EE will depend on the research question being asked, duration of investigation and resources available. Methods used to measure EE within the studies presented in this thesis are summarised in Table 2.4 along with the pros and cons of the methods reported.
Table 2.4 - Pros and Cons to the methods described along with where these methods have been used within the studies presented in this thesis

<table>
<thead>
<tr>
<th>Method</th>
<th>Pros</th>
<th>Cons</th>
<th>Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doubly Labelled Water</td>
<td>Gold standard method for measuring EE, does not interfere with habitual activity, used as a criterion validation method for estimations of EE and EI</td>
<td>Expense of isotope and laboratory analysis, no measure of activity intensity, duration, frequency, assumptions made with calculations used</td>
<td>Chapter 4, 5 + 6</td>
</tr>
<tr>
<td>Direct Calorimetry</td>
<td>Very precise measure of EE</td>
<td>Not free living, expensive, requires a purpose built chamber, skilled personal required, can only measure 1 person at a time, not suitable for young children</td>
<td>Chapter 4</td>
</tr>
<tr>
<td>Indirect Calorimetry</td>
<td>Accurate and reliable measure of EE, used as a criterion validation method for objective measures, improved field use with portable devices</td>
<td>Expensive, predominantly not free living, unsuitable for long term use, high respondent burden</td>
<td>Chapter 4, 5 + 6</td>
</tr>
<tr>
<td>Accelerometry</td>
<td>Accurate measure of EE (triaxal), PA patterns and change in activity information available, low user burden, extensively validated, unlikely to change habitual PA, suitable for children</td>
<td>Poor wear compliance, only lower body movements measured, unable to record water based activities, skill required to process and interpret accelerometry data, large number of prediction equations available, labour-intensive for downloading, recharging and servicing monitors</td>
<td>Chapter 4</td>
</tr>
<tr>
<td>Pedometry</td>
<td>Inexpensive, low user burden, suitable for all populations, easy data collection and analysis, suitable for large scale studies</td>
<td>Poor wear compliance, only lower body movements measured, unable to record water based activities, underreports low intensity PA, habitual behaviour may alter, not tamper proof, unable to assess intensity, frequency or duration of PA, poor method for estimating EE</td>
<td>Chapter 4, 5 + 6</td>
</tr>
<tr>
<td>Method</td>
<td>Advantages</td>
<td>Disadvantages</td>
<td></td>
</tr>
<tr>
<td>----------------------</td>
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<td></td>
</tr>
<tr>
<td>Heart Rate Monitoring</td>
<td>Inexpensive, suitable for most populations, low user burden for short durations, waterproof, PA can be measured at group level, good correlation to EE at high levels of PA</td>
<td>Need to pre-establish ( \dot{V}O_2 ), poor correlations to EE at low levels of PA, affected by caffeine, beta blockers, anxiety, emotion, can be uncomfortable to wear, poor wear compliance for long duration studies</td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>Allows recordings of additional qualitative measures, good for assessing young children’s PA</td>
<td>Burdensome to investigator, expensive, observer needs training, data coding is laborious, needs a controlled setting, only one measure of PA can be measured at a time, presence of observer may alter habitual PA</td>
<td></td>
</tr>
<tr>
<td>Physical Activity Log</td>
<td>Inexpensive, detailed information, PA can be quantified, patterns of activity can be identified, prospective, best subjective method for estimating EE</td>
<td>High use burden, unsuitable for young children (&lt;10 y), data processing is complex and timely, may influence habitual behaviours, estimate of EE is poor compared to objective methods</td>
<td></td>
</tr>
<tr>
<td>Questionnaires</td>
<td>Inexpensive, good for large numbers, relative ease of data collection and analysis, low respondent burden, a multiple of variables can be measured at once, individuals can be ranked, may provide location and type of activity differences</td>
<td>Recall and comprehension bias, social desirability bias, poor correlation for accurate measures of EE, not suitable for young children, need to be adapted for population under study which will then need testing for reliability and validity</td>
<td></td>
</tr>
</tbody>
</table>
2.2 Measuring Appetite

A poorly controlled appetite could impact negatively on body weight. Therefore, self-reported ratings of appetite are commonly recorded within EI studies, as it is generally presumed that there is a relationship between eating motivation and the quantity of food consumed (Sadoul, Schuring, Mela, & Peters, 2014). It is therefore necessary to ensure a valid measure of appetite is utilised.

Appetite ratings are most commonly measured through visual analogue scales (VASs; Flint, Raben, Blundell, & Astrup, 2000). VASs are also used within clinical research settings to measure a range of subjective sensations such as pain and depression (Stubbs et al., 2000). VASs are most often composed of a horizontal line (typically 100 mm) anchored at each end by words describing the extremes of the subjective feeling. The line represents a continuum, which the participants are asked to mark across reflecting the intensity of a subjective sensation at a particular time (i.e. state). This allows a quantifiable measure to be taken of a subjective feeling. An example of the VASs used within the studies presented within this thesis can be found in Appendix 10.1.

Traditionally, and within the studies presented, VASs are administered using pen and paper, which is a quick, easy and cheap method. However, the pen and paper method is not resistant to human error as each VAS needs to be entered into a spreadsheet and measuring manually, which can become laborious for the investigator.

More recently, electronic appetite rating systems (EARS) have been developed. EARS are portable handheld computers that administer electronic appetite scales. EARS are able to record the score at each time point, which can be downloaded to a spreadsheet at a later date. They also come with the added
advantage of a date and time stamp for each VAS and a reminder audio alarm which can be set throughout the day, improving compliance for use in the free living environment (Hufford and Shields, 2002). The EARS have been well validated against the traditional pen and paper VAS (Stubbs et al., 2001; Stratton et al., 1998; Whybrow, Stephen, & Stubbs, 2005; Gibbons, Caudwell, Finlayson, King, & Blundell, 2011).

When using VASs as a measure of appetite, reporting any significant changes in appetite should always be placed into context of the change in EI. Sadoul et al. (2014) reviewed 23 studies that used VAS to measure appetite with a subsequent measure of EI. Their findings indicated that there needed to be a change in a VAS score of ≥ 15 to 25 mm on a 100 mm scale for there to be any significant change in actual EI. Therefore, although appetite may significantly change according to the results from a VAS, this change may not be of a big enough magnitude to actually alter EI.

VAS are only appropriate for investigations using a within subjects design as appetite is a subjective measure. As with all subjective measures, the VASs are open to the user’s interpretation. Therefore, between-subject reliability or reproducibility comparisons are difficult to examine as a lack of agreement between scores may be due to the user’s interpretation of the scale as opposed to any actual appetite differences (Stubbs et al., 2000). If between subject comparisons are an aim for an investigation, the general Trait and State Food-Cravings Questionnaire (Nijs, Franken, & Muris, 2007) would be recommended as a more reliable method for measuring eating motivations between subjects.

An objective method that can be used to assess appetite between participants is to use biomarkers. Gut peptides such as glucose, ghrelin, cholecystokinin, glucagon-like peptide 1 (GLP-1) and leptin have all been suggested to have a
causal relationship to appetite (Mattes, Hollis, Hayes, & Stunkard, 2005). However, measuring biomarkers is much more invasive and expensive than questionnaires and requires specialist equipment for analysis.

The use of VAS for measuring appetite has not been validated in children, however the use of VAS in other contexts has (Shields, Palermo, Powers, Grewe, & Smith, 2003; McGrath et al., 1996). There is controversy within the literature regarding the age VAS are appropriate, as some level of conceptual understanding is required to successfully complete a VAS. Using a pain VAS, McGrath, De Veber, and Hearn (1985), Szyfelbein, Osgood, and Carr (1985), McGrath (1989, 1990) and Adams (1990) have suggested reliable information can be achieved from children > 5 y whereas Beyer and Aradine (1988) and Erickson (1990) suggested children needed to be > 7 y. More recently Shields et al. (2003) investigated cognitive ability as opposed to chronological age as a more accurate determinate of a child’s ability to complete a pain VAS. They concluded that cognitive ability (IQ ≥ 100) combined with chronological age (≥ 5.6 y) was the best predictor of a child’s accurate use of a VAS (88 % accuracy).

### 2.3 Measuring Eating Behaviours

Eating behaviour, particularly restrained eating, has been suggested as a variable that could potentially influence EI following exercise (Lluch, King, & Blundell, 2000). At present, to the knowledge of the author there is only 1 study (Bozinovski et al., 2009) within the paediatric literature that has investigated eating behaviour as a variable that may impact EI following exercise (see eating behaviours chapter in adults 3.1.3 and in children 3.2.7). Therefore throughout
the studies presented within this thesis, measures of eating behaviour were recorded to enhance the knowledge within this area.

There are two main questionnaires used within appetite research to classify eating behaviour in adults, the Dutch Eating Behaviour Questionnaire (DEBQ) by van Strien, Frijters, Bergers and Defares (1986) and the Three-Factors Eating Questionnaire (TFEQ) by Stunkard and Messick (1985). Within the DEBQ, eating behaviour is categorised into three types: emotional eating (eating in response to negative emotions), external eating (eating in response to sight or smell of food) and dietary restraint (eating less than desired, to lose or maintain weight, cognitively suppressing of internal hunger signals). Within the TFEQ, the focus is on restrained eating, which is categorised into three approaches: dietary restraint (the cognitive control of eating behaviour), disinhibition (tendency towards overeating motivated by the external or emotional stimuli) and hunger (the susceptibility to hunger to eat more/less). However, the TFEQ has not been developed for use within the paediatric population.

There are nevertheless two questionnaires that are specifically designed for use within the paediatric population. The DEBQ-C developed by van Strien and Oosterveld (2008), a questionnaire adapted from the DEBQ and the Children’s Eating Behaviour Questionnaire (CEBQ) developed by Wardle and colleagues (2001). The CEBQ questionnaire is designed to be completed by the parents about their child’s eating behaviours, whereas the DEBQ-C is designed to be completed by the child itself. The DEBQ-C was therefore the questionnaire of choice for measuring eating behaviour within the presented studies (chapters 4-8) for a number of reasons. Firstly, the DEBQ gives information on different types of eating behaviour and not just dietary restraint (as with TFEQ).
Secondly, following translation into various languages (Spanish: Cebolla, Barrada, van Strien, Oliver, & Baños, 2014; French: Bailly, Maitre, Amanda, Hervé, & Alaphilippe, 2012; Turkish: Bozan, Bas, & Asci, 2011; Italian: Dakanalis et al., 2013) the DEBQ has demonstrated good factorial validity and reliability. Finally it is a questionnaire that has been adapted for specific use with children aged 7-12 yrs (DEBQ-C, van Strien & Oosterveld, 2008) and does not require parental input, unlike the CEBQ.

2.3.1 Dutch eating behaviour questionnaire for children

The DEBQ was adapted for use with children (DEBQ-C) aged 7-12 y by van Strien and Oosterveld in 2008, as pilot work by Braet and van Strien (1997) found that children did not fully comprehend the items from the original DEBQ scales. An example of the DEBQ-C can be found in Appendix 10.2. The original 33 questions were reduced to 20 questions and the answers available for selection were also reduced from ‘never, seldom, sometimes, often and very often’ to just ‘no, sometimes and yes’. Seven questions were included to assess dietary restraint, seven to assess emotional eating and six questions for external eating behaviour. A score of 1 was given if the answer was no, 2 for sometimes and 3 for a yes. From the scores, an average is taken over the number of questions for each eating behaviour to generate 3 scores, one for dietary restraint, one for emotional eating and one for external eating behaviours. Scores close to 1 for each eating behaviour would indicate the individual was unrestrained, or eating was not influenced by emotion or external cues. Conversely, scores closer to 3 would indicate the individual was either highly restrained or easily influenced by emotion or external eating cues. Between the sub samples (sex and BMI-status) reliability scales (Cronbach’s Alpha) ranged from 0.73-0.82 indicating adequate to good internal consistency.
of the scales following the DEBQ-Cs development (van Strien & Oosterveld, 2008).

The Spanish DEBQ-C was administered to 240 boys and 233 girls (Baños et al., 2011). Cronbach’s alpha level ranged from 0.69 to 0.78 for the three eating behaviours. The authors noted an issue with translation of one of the questions, which when omitted increased the alpha level to 0.76 from 0.69. However similarly to Strien and Oosterveld (2008) there were no differences between age or sex with the DEBQ-C. The authors concluded the DEBQ-C was a reliable instrument for measuring eating behaviours in Spanish children.

The DEBQ-C is quick to administer and has demonstrated good reliability for measures of dietary restraint, emotional eating and external eating behaviour within children from the two studies published to date. The DEBQ-C was therefore used within all studies presented within this thesis to add an additional variable that may predict changes to EI following exercise.

2.4 Measuring Brain Activations

The study reported in chapter 8 utilised the measurement of functional magnetic resonance imagery to ascertain whether there were any brain activation differences between participants in response to visual food cues. The aim being to further understand whether there were any neurological differences between participants that may motivate or alter behaviours towards foods.

2.4.1 Magnetic resonance imagery

Magnetic resonance imagery (MRI) is a technique that has evolved following the original discovery of nuclear magnetic resonance (NMR) by Bloch (1946) and Purcell, Torrey, and Pound (1946). The first MRI scanner was built in 1977,
and in 1985 the Food and Drug Administration approved MRI for clinical use (Ashby, 2011). Magnetic resonance (MR) is still a developing field with advances in hardware and software being made continually, opening new avenues for investigation. The main advantage of using MRI over other imaging techniques such as X-rays or CT scanners is the superior contrast resolution enabling detection of small soft tissue changes. A second advantage is that MRI does not use ionizing radiation (unlike CT and X-ray), therefore it is a safe technique for use repeatedly with children.

The skull shields the anatomical structure and function of the brain and the blood-brain barrier prevents the chemical makeup of the brain being studied. The non-invasive technique of MRI has revolutionised the study of not only the brains’ structure but also the functions of the mind, for example cognitive psychology and perception (Ashby, 2011).

2.4.1.1 Theory of MRI

MRI is based on the principle that, when certain nuclei within an atom are placed within a magnetic field the nucleus can be at a range of energetic states. Hydrogen is the principle atom that has this property and given its abundance within the human body, it is the primary element used within MRI. Under normal conditions, the protons of hydrogen atoms are aligned in a random fashion (Figure 2.3).

*This image has been removed by the author of this thesis for copyright reasons.*

Figure 2.3 - Protons in random spin

However the H+ atoms can align with an external magnetic field (such as within an MRI scanner), similar to how a compass aligns with the earth’s magnetic field (Figure 2.4). MRI scanners typically have a magnetic field in the region of
1.5 - 7 T\(^2\). In comparison the Earth’s magnetic field is between 30 \(\mu\)T at the equator and 70 \(\mu\)T at the poles.

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Figure 2.4 - Protons aligned

Within a MR sample some of the protons will align with the field and some will align against the field (Figure 2.4), therefore cancelling the effect of each other out. However, there will always be a slight excess of protons aligning with the field resulting in a net alignment. The number of excess protons aligning with the field is proportional to the strength of the magnetic field.

If an electromagnetic radio frequency pulse is applied at a frequency specific to hydrogen, the hydrogen protons will absorb this energy, changing the relative proportions of protons aligned with and against the field. This gives rise to a signal that can be detected with appropriately designed receiver coils. Following the application of the radio frequency, pulse protons begin to slowly recover to their original state releasing (or retransmitting) the energy at a rate known as T1 (the longitudinal relaxation time), as well as de-phase, at a rate known as T2 (the transverse relaxation time).

\(^2\) T = Tesla, which is the unit of magnetic fields
The MR system therefore consists of the following components:

1) a large magnet which generates the magnetic field
2) shim coils which makes the magnetic field as homogeneous as possible
3) a radio frequency coil that transmits a radio frequency signal to the area being imaged
4) a receiver coil that detects the generated signal
5) gradient coils which provide spatial localisation of the signal
6) a computer that reconstructs the signal into the final image

2.4.1.2 Using the MRI scanner

Before entering the MRI scanning area, participants are required to be screened for metal, both on their person (belts, keys, coins, mobile phones) and within the body (pacemakers, stents, cochlear implants etc.) due to the strength of the magnetic field of the scanner. Subsequently, people with metal within their bodies may be unable to have an MRI scan performed safely depending on the location of the metal. Providing there are no metal related issues, the technique is very safe with no long-term harmful effects.

The MRI scan requires participants to remain very still to gain a clear image. To minimise possible movement artefacts, young children and people with claustrophobia are often sedated for scans that do not require the participant to be conscious. Where participants are required to be conscious, foam padding is used to ‘pack in tight’ the area being imaged, with the aim of minimising movement. The scanner also makes a lot of noise when the images are being taken, which can be off-putting to some participants, however noise-cancelling headphones are worn at all times.
2.4.2 Functional magnetic resonance imaging

While MRI is used to produce structural (anatomical) images of a subject’s brain, functional magnetic resonance imaging (fMRI) allows researchers to indirectly observe neural activity noninvasively in the human brain in near real time (Ashby, 2011). The aim of fMRI is to identify cerebral areas emitting a change in signal (brain mapping) in response to a well-defined external stimulus (Weishaup, Köchil, & Marincek, 2008). The functional methodology measures changes in oxygen levels of the blood in the brain following neural activity. This is based on the principle that increased neural activity requires greater energy demands which in turn increase local vasodilation and so increased blood flow. Deoxygenated and oxygenated bloods have different magnetic properties that the fMRI method capitalises on. Highly oxygenated blood is less magnetic as the oxygen is bound to the iron within hemoglobin and therefore produces a larger MR signal. Deoxygenated hemoglobin is more magnetic (paramagnetic) and so reduces the MR signal (Westbrook, Kaut Roth, & Talbot, 2011). When an area of the brain is active, a localized increase in blood flow is observed as a result of the neuronal activity. These changes in blood flow can be measured based on the brain vessels containing significant amounts of deoxyhemoglobin creating local field inhomogeneity causing a dephasing and signal loss (Westbroook et al., 2011). Images of the brain whilst at rest (no task/stimulus) are subtracted from images of the active (stimulated), resulting in regions of activity associated with the task/stimulus only being presented (Westbrook et al., 2011). This method for measuring brain activation is known as blood-oxygenation-level-dependent (BOLD) imaging, and eliminates the need for exogenous contrast agents, making this a safe non-invasive method. As an
example, Fig 2.5 shows the areas in the brain involved with visual working memory.

*This image has been removed by the author of this thesis for copyright reasons.*

Figure 2.5 - Networks within the brain working together following visual working memory stimuli (image from Pessoa et al., 2002)

Brain activation studies based on BOLD contrasts typically use an experimental paradigm, whereby the subject is exposed to alternating periods of stimulation and rest whilst a rapid series of functional MR images are collected. The variation in MR signal at each point within the brain (known as a voxel) over the time course of the experiment is then analysed to determine if the signal shows a significant correlation with the stimulus. Functional images are of a low resolution due to the speed of data collection; a whole brain volume consisting typically of ~35 parallel 2D slices, is collected in around 3 seconds. This also means that the time for both the task and rest within an experiment is required to be ≥ 3 seconds in duration so that any changes in brain activation can be captured. Anatomical images are therefore collected either before or after the experimental trial, so that they can be subsequently overlaid on the functional image to produce a more detailed functional image.

### 2.4.2.1 Processing the fMRI data

There are 5 main steps required to manipulate the raw data so it is in a format that is suitable for statistical analysis. These steps comprise of slice-time correction, motion correction, co-registration, normalisation and smoothing. These steps can be rearranged depending on the study question, however for the purpose of the analysis used within the study presented in Chapter 8, the
order was as above. Statistical Parametric Mapping (SPM (The Welcome Department of Cognitive Neurology, University College London) is the statistical software package used primarily within MRI functional research that performs the 5 steps of data manipulation as well as the statistical analysis.

2.4.2.1.1 Slice-time correction

This step is required to correct for the fact that the functional data is acquired in slices, which are not obtained simultaneously. There is often a difference of up to a few seconds in acquisition times between slices. Slice-time correction essentially shifts the phase of the time-course of the voxel within each slice to provide data, which is as if each slice had been acquired at exactly the same time. Typically (and with our study) slices are collected in an interleaved sequence such that all odd number slices are acquired first, followed by all even-number slices: 1, 3, 5, 7 … 2, 4, 6, 8 … . Slices are collected in an interleaved sequence to avoid contaminating neighbouring slices.

2.4.2.1.2 Motion correction

Despite padding around a subject’s head and verbal encouragement to remain still throughout the experiment, head movement or head drifting is inevitable. As analysis requires each voxel to correspond to a consistent anatomical point for each time point, motion correction is required. Motion correction realigns the images to a common reference (the mean). This is an important step, as movements as small as 1 % of a voxel size, particularly near strong intensity boundaries, may induce a 1 % signal change. This will also mean that your initial voxel, following motion shifting, will now occupy a new voxel space. Therefore to ensure the subject’s head occupies the same spatial coordinates throughout the experiment, movement is corrected for, based on the assumption that the brain is a rigid body and movement does not change the
shape or size of it. The position of any voxel within the brain can be identified by three coordinates (x, y, z). The movement of a rigid body (the brain) is characterised by six degrees of freedom (DOF), three translations along the x, y and z and three rotations about the x, y and z (θx, θy and θz) Figure 2.6.

As the head drift is usually in one direction, the middle slice is taken and all slices are corrected to this slice. As shown in Figure 2.7 by correcting to the middle slice, the degree of correction is smaller on each side as opposed to correcting to slice number 1 as shown in Figure 2.8 where the degree of correction for the final slice is greater. This minimises any significant alterations to the raw image by correcting to the middle slice.

Figure 2.6 - Six degrees of freedom
In the study presented in chapter 8, if there was too much subject motion (translational movement > 8 mm or rotational movement > 1.5 degrees) the data was discarded.

2.4.2.1.3 Co-Registration

Co-registration takes the individual's anatomical structural image and aligns it to the mean functional image produced from the motion correction stage.
2.4.2.1.4 Normalisation

Due to the large variation in size and shape of the brain between participants a normalisation step is required to transform individual functional images (now overlaid with the anatomical image from co-registration) to a standard brain template in order for images to be directly compared between participants. Without this step, group analysis would result in active regions of the brain being mismatched between individuals. Evans et al. (1993) within the Montreal Neurological Institute (MNI) created the most commonly used brain template, which, based on specific anatomical landmarks, matches the individuals' brain to the template.

2.4.2.1.5 Smoothing

Otherwise known as spatial filtering, smoothing is used to reduce the effects of random noise on the data and so increases the signal-to-noise-ratio (SNR). This process replaces the individual voxel intensity with a weighted average of neighbouring intensities. The difference between activation areas within the brain pre- and post-smoothing can be seen in Figure 2.8 and Figure 2.9. This is the final step in the processing of the raw data.

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Figure 2.9 - Unsmoothed data (images from Duke-UNC Brain Imaging and Analysis Centre 2003 handout).

This image has been removed by the author of this thesis for copyright reasons.
Figure 2.10 - Smoothed data (kernel width 5 voxels) (images from Duke-UNC Brain Imaging and Analysis Centre 2003 hand-out).

Following these above steps, the data is now in a suitable format for statistical analysis, enabling comparisons both between conditions and subjects.
3 Literature Review: Current Findings

3.1 Current Literature in Adults

The first recorded study to examine the effects of daily EE on EI was published in 1956 by Mayer, Roy, and Mitra. Since this time there has been a multitude of research within this area in adults (later studies have included measures of appetite) and have since been reviewed, most recently by Elder and Roberts (2007), Martins et al. (2008), Bilski, Teleglów, Zahradnik-Bilska, Dembiński and Warzecha (2009) and Schubert, Desbrow, Sabapathy, and Leveritt (2013). The studies from within these reviews, mainly experimental in design, have shown high individual variance. Researchers have therefore been unable to deduce a general response as to how an imposed increased EE may alter acute EI and appetite. However some trends do seem to be apparent based on particular methodological and participant characteristics. Methodological characteristic differences include the exercise intervention (intensity undertaken), timings of measurements (imposed exercise bout and subsequent eating opportunity) and macronutrient composition of food available. Typical participant characteristic differences include sex, innate eating behaviours, habitual exercise patterns and body size. How an increased EE alters EI and appetite in adults, dependent upon these factors, will be discussed within this chapter with pertinent key papers cited in detail to highlight the main findings.

3.1.1 Exercise intensity

The intensity of the exercise undertaken is a primary variable associated with changes in both EI and appetite. The majority of studies have shown vigorous/high intensity exercise (>60 % maximum oxygen consumption) will
elicit a reduction in hunger, (Thompson, Wolfe, & Eikelboom, 1988; King, Burley, & Blundell, 1994; King & Blundell, 1995; King, Snell, Smith, & Blundell, 1996; Westerterp-Plantenga, Verwegen, IJedema, Wijckmans, & Saris, 1997) and/or a reduction in EI (Kissileff, Pi-Sunyer, Segal, Meltzer, & Foelsch, 1990; Imbeault, Saint-Pierre, AlméRas, & Tremblay, 1997) or increase in EI (Pomerleau, Imbeault, Parker, & Doucet, 2004).

The following discussion on exercise intensities has focused on four studies that have specifically compared two exercise intensities within their study design. Three of these studies have compared two exercise intensities that were matched for the EE (Thompson et al., 1988, Imbeault et al., 1997 and Pomerleau et al., 2004) whilst Kissileff et al., (1990) compared duration matched differing exercise intensities. Table 3.1 presents a summary of these studies and their comparative exercise intervention.

Thompson et al. (1988) compared high intensity exercise (HIE) (cycling for 23-35 min at 68 % \( \dot{V}O_{2\text{max}} \)) and low intensity exercise (LIE) (cycling for 46-70 min at 35 % \( \dot{V}O_{2\text{max}} \)) energy matched at 17 kJkg\(^{-1}\) in young males. Perceived hunger in the HIE condition was suppressed by 1 point (on a 9 point scale) compared to the control and LIE conditions, which were similar. However this suppression was acute, as hunger ratings recovered to the same levels as LIE and control by the time the meal was administered (50 min post exercise). No significant changes in total EI between the conditions was found, although there was a significant increase in energy consumed from liquid sources following both the HIE and LIE conditions (~200 kJ increase). However it should be noted that all fluid available for consumption contained energy (cartons of milk and juice), and a non-energy containing beverage was not offered. This suggests
that the increase in EI from fluids following the exercise conditions was more likely driven by thirst and the participants rehydrating themselves than a specific change in EI requirements.

Imbeault et al. (1997) compared HIE (running for 34 ± 6 min at 75 % $\dot{V}O_{2\text{max}}$) to LIE (walking for 72 ± 14 min at 35 % $\dot{V}O_{2\text{max}}$) in males, energy matched at 2050 kJ. No significant appetite differences between conditions were found, although there was a trend for hunger to increase following LIE (74 mm to 93 mm) and fullness to reduce (60 mm to 26 mm). EI was not significantly different between conditions, however relative EI (relative EI = total EI – exercise EE) was significantly reduced following both the LIE (mean EI: 5719 ± 1000 kJ) and HIE (mean EI: 4796 ± 1000 kJ) compared to the control condition (mean EI: 6593 ± 1000 kJ).

Kissileff et al. (1990) also undertook an exercise intensity comparison study (strenuous at 90 W (mean EE 1030 ± 100 kJ) or moderate 30 W (mean EE 480 ± 150 kJ)) but in females. The two intensities were not energy-matched, rather they were duration-matched to 40 min. Compared to EI in the control condition (mean intake: 3081 ± 1325 kJ), EI was reduced (although not significantly) following the strenuous exercise (2701 ± 1422 kJ) and increased (again not significantly) following the moderate exercise (3279 ± 1094 kJ). There was however, a significant decrease in EI following the strenuous exercise when compared to the moderate condition. No significant changes in hunger were found between conditions, however hunger was only measured once over the test period: 5 min after cessation of the test meal. Assessing appetite after participants had had *ad libitum* access to food is an unusual time to capture changes in appetite sensations, particularly as assessing appetite is a simple
and inexpensive measure. Poor timing for capturing any potential appetite changes is a large limitation to the study.

Pomerleau et al. (2004), again in females, compared HIE (running for 37.0 ± 4.6 min at 70 % \( \dot{V}O_{2\text{peak}} \)) and LIE (walking for 64.7 ± 7.9 min at 40 % \( \dot{V}O_{2\text{peak}} \)), energy matched at 1500 kJ. Unlike Kissileff et al. (1990) and Imbeault et al. (1997), EI was found to significantly increase following the HIE (3.67 ± 1.30 MJ) compared to the control condition (3.14 ± 0.96 MJ), but no significant differences were found between conditions for the LIE (3.43 ± 0.99 MJ). No significant changes to appetite were observed between conditions, however appetite was assessed immediately before exercise and 1h post exercise and not immediately following the exercise, which is the time window in which previous studies have indicated acute changes in appetite to occur (Thompson et al., 1988; Westerterp-Plantenga et al., 1997).

Table 3.1 - Summary of the studies reviewed comparing exercise intensity

<table>
<thead>
<tr>
<th>Author</th>
<th>Sex</th>
<th>Mode of exercise</th>
<th>High Intensity Exercise</th>
<th>Low Intensity Exercise</th>
<th>Energy Intake</th>
<th>Appetite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thompson et al.</td>
<td>M</td>
<td>Cycling</td>
<td>23-35 min at 68 % ( \dot{V}O_{2\text{max}} )</td>
<td>46-70 min at 35 % ( \dot{V}O_{2\text{max}} )</td>
<td>No change</td>
<td>Reduced hunger</td>
</tr>
<tr>
<td>Imbeault et al.</td>
<td>M</td>
<td>Walking/Running</td>
<td>34 ±6 at 75 % ( \dot{V}O_{2\text{max}} )</td>
<td>72 ±14 at 35 % ( \dot{V}O_{2\text{max}} )</td>
<td>Relative EI reduced</td>
<td>No change</td>
</tr>
<tr>
<td>Kissileff et al.</td>
<td>F</td>
<td>Cycling</td>
<td>40 min at 90 W</td>
<td>40 min at 30 W</td>
<td>HIE reduced compared to LIE</td>
<td>No change</td>
</tr>
<tr>
<td>Pomerleau et al.</td>
<td>F</td>
<td>Walking/Running</td>
<td>37 ±5 min at 70% ( \dot{V}O_{2\text{peak}} )</td>
<td>65 ±8 min at 40% ( \dot{V}O_{2\text{peak}} )</td>
<td>Increased following HIE</td>
<td>No change</td>
</tr>
</tbody>
</table>

It appears that HIE is more likely to alter EI or appetite than LIE in both males and females. Whether there is an increase or decrease in EI may be dependent
on the sex of the participants and/or the mode of exercise. Elder and Roberts (2007) suggested that a change in EI may be a result of an individual’s level of fat oxidation as based on work by Alméras, Lavallée, Després, Bouchard, and Tremblay (1995). Alméras et al. (1995) showed that lower increases in EI following exercise were associated with individuals who had a greater fat oxidation during the exercise. However, carbohydrate oxidation was not found to correlate to any changes to EI post exercise (Alméras et al., 1995). Further investigations into different exercise intensities and modalities requires further attention within the adult literature.

### 3.1.2 Sex differences

It has previously been well documented that following exercise-induced weight loss programmes males are more likely to lose more weight than females (Meta-Analysis: Ballor & Keesey, 1991; review: Hagobian & Braun, 2010) who either lose or gain weight (Donnelly et al., 2003; Potteiger, Jacobsen, & Donnelly, 2003). However, a more recent systematic review has suggested that there are no sex differences to body weight changes in response to exercise when the energy expended through exercise between the sexes is equivalent (Caudwell, Gibbons, Finlayson, Näslund, & Blundell, 2014). Instead Caudwell and colleagues (2014) suggested that the increased loss in body weight observed in males could be attributed to a greater exercise-induced EE, rather than an increase in compensatory eating in females as previously suggested.

From the studies previously mentioned within exercise intensity (chapter 3.1.1); following HIE both appetite (Thompson et al., 1988) and EI (Imbeault et al., 1997) were reduced in males, whereas Pomerleau et al. (2004) indicated an increase in EI following HIE in females. Additional acute studies have reported
that in males, following both cycling and running exercise at 70 % \( \dot{V}O_{2\text{max}} \), hunger was suppressed and a delay in the onset of eating was recorded when compared to the control condition. No significant differences in total EI were found between the conditions (King and Blundell, 1995). In contrast, females following cycling exercise at 70 % \( \dot{V}O_{2\text{max}} \) indicated no significant appetite or EI changes compared to a control condition (King et al., 1996). Finally, following 120 min of treadmill exercise, hunger was shown to decrease significantly immediately post exercise (~20 mm reduction on 100mm VAS) when compared to the control condition in males. This hunger suppression remained apparent at 60 min post exercise (~10 mm reduction). However, this suppression in hunger failed to impact EI as there were no significant changes to EI between conditions (Vatansever-Ozen, Tiryaki-Sonmez, Bugdayci, & Ozen, 2011).

Primarily the literature is indicating that exercise may significantly alter acute appetite, but this change in appetite may not necessarily lead to any alterations in acute EI.

There is also evidence for sex differences from a longer 9-day energy balance study reported by Stubbs and colleagues from combining their findings in males (Stubbs et al., 2002a) and females (Stubbs et al., 2002b). Days 1 and 2 of their intervention imposed a maintenance diet whilst an ad libitum diet was recorded over the following 7 days. Cycling exercise was implemented on days 3-9. There were three conditions, no exercise, moderate exercise (two 40 min exercise sessions, total EE 2.6 ± 0.2 MJ/d for the male and 1.9 MJ/d for the females) and high exercise (three 40 min exercise sessions, total EE 4.7 ± 0.3 MJ/d for the males and 3.4 MJ/d for the females). No significant changes in EI between conditions for the male participants were found, whereas the females
significantly increased their intake from 8.9 MJ/d on the no exercise condition to 10.0 MJ/d on the high exercise condition. Following the moderate exercise condition, mean EI was not altered significantly from the control condition (9.2 MJ/d) for the females. There were no significant differences in appetite ratings between conditions for either sexes, however the mood of the females was improved following the exercise, an occurrence not apparent with the males. These findings suggest that males are better able to tolerate a negative energy balance (i.e. they do not demonstrate compensation for the energy deficit by increasing the EI) following an imposed increase in EE compared to females.

Elder and Roberts (2007) previously suggested that there were differences in macronutrient preferences between the sexes following exercise. Males appeared to decrease their fat intake as habitual activity levels increased whereas females increased their fat intake with rising habitual activity levels. This theory was corroborated in males (but not females) by Ebrahim, Rahmani-Nia, Damirchi, Mirzaie and Pur (2013) who imposed 5 days of forty-five minutes of daily running exercise at 55 % of maximum HR reserve on 8 males and 8 females. EI was then compared to a 5 d control condition. There were no significant differences in EI between the conditions, however females compensated 22.9 % of the EE by the exercise whereas the males did not alter their EI to compensate for the energy deficit (-10.2 % of EE). Relative energy intake (EI – EE) was therefore unsurprisingly significantly reduced in the males following the exercise condition (8.0 MJ/d) compared to the control condition (9.3 MJ/d). There were no significant differences for relative EI between conditions for the females. Males also significantly altered the macronutrient composition of their EI following exercise, opting for significantly greater intake
from fat (35 % compared to 32 %) and reduced intakes of carbohydrate (50 % compared to 55 %). The macronutrient composition for the females between conditions was unchanged. There were no significant appetite changes between conditions for either sex. Within this study reported fasting levels of plasma leptin were significantly higher in females (~15 ng/mL) compared to fasting levels in males (~2ng/mL) for both conditions, an expected finding between the sexes based on the work by Kennedy and colleagues (1997). Following exercise there was a significant reduction in insulin (~2 micIU/mL) in the females only. High levels of leptin are renowned for increasing sensations of satiety. Plasma ghrelin and glucose levels were not significantly different between conditions or sexes. Ebrahimi and colleagues (2013) concluded that females were more sensitive to a negative energy balance and responded to an exercise induced energy deficit by increasing their EI and altering the energy-regulating hormones, more so than males. Consequently they suggested that females might need to both increase EE and decrease EI to lose body fat, although further research would be needed to support this theory.

As indicated by Ebrahimi and colleagues (2013), sex differences following exercise may be attributed to hormonal differences between the sexes. Hagobian and Braun (2010) investigated changes in 3 appetite related hormones: plasma acylated ghrelin, insulin and leptin following exercise over 4 days in males and females. There were two conditions within the study – energy balanced (where EI was increased to match the EE) and energy deficit (where EI was not increased to match the EE). The EE was 30 % of total daily EE, elicited by moderate intensity exercise (50-65 % \( \dot{V}O_{2peak} \)), this exercise amounted to ~3.1 MJ of EE for males over a duration of 83 ± 8 min and ~2.5 MJ
for females over a duration of 89 ± 5 min. Appetite (desire to eat and hunger) was significantly reduced (very weak desire for food and reduced hunger) in the energy-balanced condition compared to the energy deficient condition (~20 mm reduction for both) in males. The energy deficit had no effect on the females’ appetite. Following either exercise condition (although attenuated in the energy balanced condition) females responded to the imposed exercise with an increased acylated ghrelin (AUC ~1000 pg/mL*min) and decreased insulin level (AUC ~1500 pM*min) more so than the males. Such changes in these hormones are associated with EI stimulation. These findings suggest that the mechanism controlling EI, and so in turn maintaining body fat, is more effective in females than males. Preserving body fat in females could be an intrinsic mechanism as energy deficiency inhibits reproductive success whereas for males reproductive success is not energy dependent (Wade and Jones, 2004). Hagobian and Braun (2010) summarised further studies investigating appetite hormone changes following exercise between the sexes and concluded that exercise evokes a larger change in the energy-regulating hormones in females than males. Hagobian and Braun (2010) also determined that the directional change in the energy-regulating hormones following exercise would stimulate appetite in females. A hypothetical model of how exercise alters appetite-regulating hormones between the sexes is shown in Figure 3.1.

In addition to appetite regulating hormones differing between sexes following exercise, it should also be noted that sex hormones also alter energy balance. A reduction in oestrogen has been associated with an increase in EI and fat intake (Buffenstein, Poppitt, McDevitt, & Prentice, 1995). Buffenstein et al. (1995) findings indicate that EI may be altered depending on where a woman is within her menstrual cycle. Control for the menstrual cycle within females is not
often considered within EB studies. However Hogabian et al. (2009) did consider the phases of the menstrual cycle, ensuring females recruited to their study were tested 1 to 4 days after menstruation (the early follicular phases of the cycle).

It is clear that the way EE impacts appetite and EI patterns can be sex specific. A review by Bilski et al. (2009) suggested that females would increase their EI following an exercise session to almost totally compensate for the exercise induced increase in EE. It was suggested by King et al. (1996) that a negative energy balance would be favoured following light exercise in females and intensive exercise in males. Further investigations are required however to broaden the understandings of these potential sex differences. Whether sex specific PA recommendations should be reflected upon within public health guidelines also requires further consideration.

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Figure 3.1 - Hypothetical model of how physical activity impacts hormonal appetite regulation of energy balance in males and in females. Reproduced from Hagobian and Braun (2010) pp 29.

3.1.3 Eating behaviour

Eating behaviour, particularly restrained eating, has been suggested as a variable that could potentially influence EI following exercise (Lluch et al., 2000). Controlling for eating behaviours is still a novel concept within the literature and to date has been used primarily to recruit participants with specific eating behaviours (King et al., 1996; Martins et al., 2008; Keim, Canty, Barbieri, & Wu, 1996; Bryant, King, & Blundell, 2005; Bryant, Finlayson, King, & Blundell,
There have only been a few studies that have recruited and compared participants with opposing eating behaviours. Lluch et al. (2000) compared female restrained eaters (TFEQ mean score 13.3 ± 2.5) to female unrestrained eaters (TFEQ mean score 4.4 ± 3). Participants completed 50 min of cycling exercise at 70 % $\dot{V}O_{2\text{max}}$ followed by either a high fat or low fat test meal; resulting in 4 conditions, rest high-fat, rest low-fat, exercise high-fat, exercise low-fat. There were no significant differences between the exercise or rest conditions for EI with either restrained or unrestrained eaters, indicating the increased EE from the imposed exercise was not compensated for by a change in EI. Interestingly however, it was found that in the rest conditions, EI was significantly higher in the restrained eaters (high fat: 5.1 ± 1.0 MJ; low fat: 3.2 ± 0.5 MJ) compared to the unrestrained eaters (high fat: 4.5 ±0.8 MJ; low fat: 2.7 ± 0.5 MJ). No significant differences between the groups for EI were found for either exercise high-fat or exercise low-fat. It was also reported that exercise was more effective at creating an energy deficit in the restrained eaters compared to the unrestrained eaters. Dietary restraint might therefore influence exercise by acting as a controlling mechanism to prevent over eating as opposed to a disinhibitor to eating. Finally food hedonic ratings were measured (the pleasantness, palatability and tastiness; Lluch et al., 2000). Following the high-fat lunch, pleasantness was rated significantly higher in the restrained individuals compared to the unrestrained individuals. The perception of the pleasantness, tastiness and palatability of the foods was significantly higher following exercise when compared to the rest condition, independent of dietary restraint.

Bryant et al. (2005, 2006) recruited females with low-disinhibition (LD) and high-disinhibition (HD) (disinhibition scores not available) and assessed their EI,
appetite (2005) and food preferences (2006) in a control and exercise condition (cycling at 70 % $HR_{max}$ for 50 min). Exercise increased fullness and decreased hunger and desire to eat for HD more so than the LD (2005). HD rated the test meal ‘more tasty’ for the exercise condition although total EI was unchanged (Bryant et al., 2005). HD was also associated with a significantly greater liking for all food stimuli and a higher preference for high fat foods (Bryant et al., 2006). However, following exercise HD was associated with a significant increase for preferences for low-fat foods and a reduced motivation to eat (Bryant et al., 2006). These findings suggest scores of disinhibition may impact the way an individual responds to food following an imposed bout of exercise.

Exercise-induced changes in food reward have also been indicated by Finlayson et al. (2009) following a bout of cycling exercise at 70 % $HR_{max}$ for 50 min. Changes to EI following the exercise condition identified two groups within the participants: non-compensators - those who did not alter their EI following exercise and compensators - those who increased their EI following exercise. Compensators in addition to increasing their EI, also rated their food more palatable, indicated an increased wanting of food following exercise, as well as, an increased preference for high-fat sweet foods compared to non-compensators. Understanding whether there is an enhanced motivational drive for wanting food following exercise may explain some of the individual differences observed between participants. Identifying and characterising psychological markers of eating behaviour may improve the efficiency of exercise prescription as a tool to promote weight loss. Further investigations are required within the adult literature considering both physiological and psychological predispositions, which may control EI compensation following imposed EE.
3.1.4 Habitual exercise

It has been proposed that habitual exercisers have increased appetite sensitivity compared to inactive individuals (Bilski et al., 2009). Bilski et al. (2009) suggested the increased sensitivity of satiety signalling may be attributed to the increase in insulin sensitivity associated with habitual exercise. This is a hypothesis that still requires further investigation.

Differences between habitual and non-habitual exercisers have been investigated in studies as early as 1956. Mayer, Roy and Mitra monitored EE and EI in mill workers categorising them according to their level of occupational PA. An increase in EI was shown when estimated energy requirements increased, however, the rise in EI was only observed in the groups performing activity above a threshold level. Those workers who performed sedentary activities, did not decrease their EI in proportion to the decrease in EE, but instead had intakes similar to those at higher expenditures leading to positive energy balance. This early work was the first suggestion that increased sedentariness may invoke poor appetite control.

Whether activity related EE (AREE) impacted on appetite and EI at an ad libitum buffet meal was investigated by Harrington, Martin, Ravussin, and Katzmarzyk (2013) in both males and females. AREE was determined as the residual value of the regression between total daily EE and 24-h resting EE where a positive AREE indicated high levels of EE through PA. Appetite scores taken preceding a test meal, were significantly higher in the males from the lowest tertile of AREE (increase in hunger ~10 mm, desire to eat ~19 mm, prospective food consumption ~9 mm and a decrease in fullness ~15 mm) compared to the males in the highest tertile. No significant differences between
appetite scores were found between the female participants in any of the tertiles. Males in the middle AREE tertile had a significantly reduced intake (3.6 ± 0.4 MJ) during a test meal compared to the highest (5.7 ± 0.4 MJ) and lowest tertiles (4.6 ± 0.5 MJ). Thus, not only were sex differences found within this study, but also differences between participants with different levels of habitual PA.

Further energy balance studies have also concluded that habitual exercisers are better able to increase their EI to match their higher EE demands (Horton et al., 1994; Maughan, Robertson, & Bruce, 1989; Saris, van Erp-Baart, Brouns, Westerterp, & Ten Hoor, 1989). Although other studies have indicated that habitual exercisers (primarily professional or elite athletes) fail to meet the increased energy demands of their training and are therefore often in negative energy balance (Alméras, Mimeault, Serresse, Boulay, & Tremblay, 1991; Beidleman, Puhl, & De Souza, 1995; Edwards, Lindeman, Mikesky, & Stager, 1993; Doyle-Lucas, Akers, & Davy, 2010; Russell & Pennock, 2011).

More specifically to this thesis, short term EI regulation was investigated in habitual and non-habitual exercisers (Long, Hart, & Morgan, 2002). Habitual exercisers were shown to have an increased accuracy (90 % compensation) for short-term regulation of EI compared to non-regular exercisers (7 % compensation) 60 min after a high carbohydrate preload drink (Long et al., 2002). Similar findings were also found by Van Walleghen, Orr, Gentile, Davy, and Davy (2007) where following a high-energy preload drink over the course of the day, habitual exercisers were better able to compensate (compensation 100 ± 5 %) for the increased EI compared to the sedentary individuals (compensation: 79 ± 6 %). Interestingly Van Walleghen and colleagues found
that the young (21-35y) participants were better able to compensate for the increased EI (81 ± 4 %) compared to the older (60-80y) participants (65 ± 4 %). In addition to an increased ability to regulate EI following exercise in habitual exercisers, a change in macronutrient composition has also been indicated. Elder and Roberts (2007) reported a trend for an increase in carbohydrate and decrease in fat and protein intake with male habitual exercisers compared to male non-exercisers. In contrast, active females tended to increase their fat intake compared to non-active females (see review by Elder & Roberts, 2007).

Consideration to the habitual exercise patterns of participants recruited to studies should be addressed within future research, as there remains a paucity of knowledge surrounding the acute effects of exercise on EI in habitual and non-habitual exercisers. More research into why and how habitual exercisers can regulate their EI post exercise more accurately when compared to non-habitual exercisers still requires further investigation.

3.1.5 Body size

Body size has also been suggested as a confounding variable that may alter the EI and appetite responses to an imposed exercise bout. In the Kissileff et al. (1990) study mentioned previously in chapter 3.1.1 overweight participants (BMI: 27.72 ± 0.90 kg/m²) were also recruited to their investigation. Unlike lean females who reduced their intake following HIE, the overweight participants did not significantly change their EI between conditions. However interestingly, EI was lower (326 – 744 kJ) although not significantly in the overweight compared to the lean participants for all conditions. There were also significant changes for hunger in the overweight participants, whose hunger increased to 25 mm
(on a 150 mm VAS) following exercise in the LIE condition when compared to the HIE (10 mm) and control (14 mm) conditions. No significant changes to appetite were observed within the group of lean participants.

EI and appetite has also been compared over 6 days, in a live-in facility between obese (BMI: 37.6 ± 7.5 kg/m²) and lean (BMI: 21.8 ± 2.1 kg/m²) participants (Durrant, Royston, & Wloch, 1982). On 3 consecutive days the participants were required to complete 1000 revolutions of cycle exercise (~420 kJ/d) and on the other 3 days, to rest. Participants’ food was dispensed from machines that recorded the amount of food being dispensed at each eating occasion. The lean participants increased their EI on the exercising days (EI increase 650 kJ/d) an overcompensation of ~230 kJ/d, whereas the obese group decreased their EI (EI decrease 75 kJ/d). There were no significant differences for EI between the groups on the rest days. Durrant and colleagues (1982) concluded that the lean participants were able to regulate EI more accurately to meet energy balance (following the imposed increase in EE) than the obese participants. Appetite scores were lower for all participants with exercise compared to the rest condition (data not reported), interestingly this decrease was more pronounced with the obese participants and may suggest why the obese participants did not increase their EI to the same extent as the lean following exercise. However, it should be noted that there were 12 participants (11 female 1 male) in the obese group and only 4 participants (3 female and 1 male) within the lean group therefore definitive conclusions cannot be made from such small and uneven sample sizes.

Whether obesity status may impact appetite through differences in gut hormone regulation of appetite has also been investigated. Ueda, Yoshikawa, Katsura, Usui, & Fujimoto (2009) examined whether aerobic exercise altered gut
hormone release (peptide YY (PYY) and glucagon-like peptide-1 (GLP-1) both appetite supressing hormones and plasma ghrelin an appetite stimulating hormone) differently between young obese and normal weight males. PYY and GLP-1 both increased as a result of the exercise, whereas plasma ghrelin levels were unaffected, these changes in hormones were unaffected by the obesity status of the participants.

Finally, Westerterp-Plantenga et al. (1997) found temporary reductions in hunger and a decrease in EI in both normal weight and obese males following 2 h of moderate cycling exercise. There were no significant differences between the normal weight or obese groups for EI or appetite.

These findings are equivocal, although there is a strong possibility that there is an interaction between body size and sex on post exercise changes to EI and appetite, warranting consideration to the participants’ body size within any future research investigations. Differences in weight status were however not investigated within the studies presented in this thesis due to the magnitude of other variables associated with influencing EI and appetite following imposed EE, that were subsequently investigated.

3.1.6 Timings of measurements

It has been hypothesised for studies showing an acute decrease in EI in the meal post exercise, that EI could potentially be increased later that day or over the following weeks (Martins et al., 2008). Verger, Lanteaume, and Louis-Sylvestre (1992) compared EI following 120 min of submaximal exercise (~70-80 % of maximal HR, EE ~2.1 MJ) when the test meal was offered on four time occasions: 0, 30, 60 and 120 min following an exercise session and also following a sedentary condition. The meal consumed 60 min after the 120 min
exercise bout was significantly larger (by ~2.0 MJ) than the meal consumed at the same time in the sedentary condition. Interestingly the increase in EI at 60 min post exercise was well matched to the EE from the imposed exercise. Following exercise, the later the meal was presented post exercise, the larger the volume of food that was consumed; although this was only significant between time points 0 to 60 min, and 0 to 120 min.

Whether the time of day (morning or afternoon) impacts EI or appetite was investigated by Maraki et al. (2005), following a 1 h aerobic and muscle conditioning exercise class. No significant differences were found between exercise conditions (morning or afternoon) with an average EE of exercise ~1.2 ± 0.1 MJ, although the rate of perceived exertion of morning exercise bout was higher (~2 on the Borg scale of 6-20 (Borg 1985)) compared to the evening exercise bout. This may possibly be attributed to natural circadian rhythms. Hunger and prospective food consumption were significantly increased and satiety and fullness were significantly decreased by both exercise conditions irrespective of the time of day the exercise bout was performed. There were no significant changes to EI between conditions. The authors concluded that the time of day for a bout of exercise had no impact on EI and appetite scores, however the time of day did impact upon the perceived exertion of the session. Reflections upon the timings for a study of similar natures should be carefully considered dependent on the variables under investigation.

### 3.1.7 Macronutrient composition of food choices available post exercise

Macronutrient changes to food choice following exercise have already been discussed within sex differences in chapter 3.1.2 in the study by Ebrahimi et al. (2013) who found males increased fat and decreased carbohydrate intake
following exercise. Similarly within habitual exercisers in chapter 3.1.4 Elder and Roberts (2007) summarised that habitual exercisers had an increased intake of carbohydrate and decreased fat and protein within their diets compared to non habitual exercisers. Further studies showing changes to macronutrient intake following exercise include Westerterp-Plantenga et al. (1997) who found males increased their carbohydrate intake after 2 h of cycling compared to a control condition. Conversely females were found to increase their intake of fats and proteins immediately after 75 min of high intensity walking exercise compared to a control condition (Pomerleau et al., 2004).

Changes to macronutrient composition appear to be apparent following a bout of exercise when self-selection of food is available. However, these changes are not consistent between studies. Homogenised test meals or minimal choices within a test meal are therefore suggested where the aim of the study is to look at total energy compensation to prevent any changes in satiety and therefore absolute EI as a result of macronutrient hierarchy. For example, protein foods have been shown to be weight for weight more satiating than predominantly carbohydrate based food (Westerterp-Plantenga, Nieuwenhuizen, Tome, Soenen, & Westerterp, 2009; Veldhorst et al., 2008).

3.1.8 Summary

Appetite is more commonly reported to be suppressed or eating delayed immediately post exercise (exercise induced anorexia; Elder & Roberts, 2007). However, appetite suppression most often does not translate into an actual
change in EI. Elder and Roberts (2007) also suggest that any decrease in appetite suppression is acute (approx. 1 hr). A recent meta-analysis by Schubert et al. (2013) found that following a bout of exercise when compared to a control condition, 28 trials indicated a changed in EI of ±400 kJ, whilst 17 showed an increase of more than 400 kJ and 6 showed a decrease of more than 400 kJ. Similarly an earlier review by Bilski et al. (2009) from 12 papers investigating EI following exercise, showed eight studies found no change to total EI following exercise whilst two showed an increase and two a decrease. With such equivocal findings, further research is required within this complex area. A recommendation that all the variables mentioned within this chapter should be considered when planning future investigations has been made as they all may impact the findings in some way.
3.2 Current Literature In Children

In comparison to the adult literature there is a paucity of research investigating acute changes to EI and/or appetite following an increase in exercise-induced EE in children. Both PA levels (Telama et al., 2005; Dohle & Wansink, 2013) and eating behaviours (Mikkilä et al., 2005) track closely from childhood to adulthood and more specifically from adolescence to adulthood (Kelder, Perry, Klepp, & Lytle, 1994). It is imperative that investigations are performed within the paediatric population since this information can be used to understand energy regulating behaviours that could maintain appropriate weight stability into adulthood.

To date, to the best of our knowledge, there are 10 published studies investigating the acute effects of exercise on EI and/or appetite in children. From these 10 studies, 4 recruited normal weight children (Bellissimo, Thomas, Goode, & Anderson, 2007; Bozinovski et al., 2009; Moore, Dodd, Welsman, & Armstrong, 2004; Rumbold, St Clair Gibson, Stevenson, & Dodd-Reynolds, 2011), 3 recruited both normal weight and overweight or obese children (Dodd, Welsman, & Armstrong, 2008; Nemet, Arieli, Meckel, & Eliakim, 2010; Tamam, Bellissimo, Patel, Thomas, & Anderson, 2012) and 3 recruited just obese children (Thivel et al., 2011a; 2011b and 2012). The focus of this thesis is on normal weight children, and therefore the main attention of this chapter will also be focused upon the responses from the normal weight children in the 7 published studies, a summary of which is presented in Table 3.2.
<table>
<thead>
<tr>
<th>Study</th>
<th>Age (years)</th>
<th>Sample (participant number)</th>
<th>Exercise</th>
<th>EI</th>
<th>Appetite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bellissimo et al. 2007</td>
<td>9 to 14</td>
<td>NW Boys (n=14)</td>
<td>12 min walking</td>
<td>Not reported</td>
<td>Increased average appetite and PC</td>
</tr>
<tr>
<td>Bozinovski et al. 2009</td>
<td>9 to 14</td>
<td>NW Boys (n=14)</td>
<td>15 min walking at VT</td>
<td>No change</td>
<td>Decreased appetite, DTE and hunger. No change fullness and PC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NW Girls (n=15)</td>
<td>45 min walking at VT</td>
<td>No change</td>
<td>Increase appetite DTE and hunger. No change fullness and PC</td>
</tr>
<tr>
<td>Dodd et al. 2008</td>
<td>11.5 ± 0.4</td>
<td>NW Girls (n=6)</td>
<td>Cycling at 75% VO_{2max}</td>
<td>No change</td>
<td>Decrease fullness increase hunger no change to DTE</td>
</tr>
<tr>
<td></td>
<td></td>
<td>OW Girls (n=6)</td>
<td>Duration set to expend 0.75 MJ</td>
<td>No change</td>
<td></td>
</tr>
<tr>
<td>Moore et al. 2004</td>
<td>9 to 10</td>
<td>NW Girls (n=19)</td>
<td>Cycling at 50% VO_{2max}</td>
<td>Reduced compared to exercise at 75% VO_{2max}</td>
<td>No change Reduced PC compared to 50% VO_{2max} and rest conditions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Duration set to expend 1.5 MJ</td>
<td>No change</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cycling at 75% VO_{2max}</td>
<td>No change</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Duration set to expend 1.5 MJ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nemet et al. 2010</td>
<td>6 to 11</td>
<td>NW Boys (n=5)</td>
<td>45 min of aerobic exercise, resistance-type exercise and swimming</td>
<td>Reduced following all exercise types compared to control, but only significantly for resistance-type exercise</td>
<td>Not assessed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NW Girls (n=17)</td>
<td></td>
<td>Increased following exercise compared with control, but only significantly for swimming exercise</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>OB Boys (n=7)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>OB Girls (n=15)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study</td>
<td>Age Range</td>
<td>Group Description</td>
<td>Exercise Description</td>
<td>Behavioral Response</td>
<td></td>
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<td>-------------------------------------------------------------------------------------</td>
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</tr>
<tr>
<td>Rumbold <em>et al.</em></td>
<td>13 to 15</td>
<td>NW Girls (n=11)</td>
<td>47 min netball exercise</td>
<td>Increased compared to sedentary condition</td>
<td></td>
</tr>
<tr>
<td>Tamam <em>et al.</em></td>
<td>9 to 14</td>
<td>NW Boys (n=18)</td>
<td>15 min walking at VT 15 min walking at 25% above VT</td>
<td>No change following either walking at VT or 25% above VT</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>OW/OB Boys (n=17)</td>
<td></td>
<td>Increased appetite, DTE, PC, thirst and hunger, decreased fullness for walking at VT and 25% above VT</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>No change following walking at VT (25% of VT not assessed)</td>
<td></td>
</tr>
<tr>
<td>Thivel <em>et al.</em></td>
<td>14.4 ± 1.5</td>
<td>OB Boys (n=5) OB Girls (n=7)</td>
<td>30 min cycling at 70% VO2max</td>
<td>Reduced compared to control</td>
<td></td>
</tr>
<tr>
<td>Thivel <em>et al.</em></td>
<td>14.1 ± 1.8</td>
<td>OB Boys (n=7) OB Girls (n=7)</td>
<td>30 min cycling at 70% VO2max</td>
<td>Reduced compared to control</td>
<td></td>
</tr>
<tr>
<td>Thivel <em>et al.</em></td>
<td>13.5 ± 0.9</td>
<td>OB Boys (n=15)</td>
<td>63 min cycling at 40% VO2max 33 Min cycling at 75% VO2max</td>
<td>No change</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Reduced compared to control and cycling at 40% VO2max</td>
<td></td>
</tr>
</tbody>
</table>

NW = normal weight; OB = obese; OW = Overweight; PC = prospective consumption; DTE = desire to eat; VT = ventilatory threshold
3.2.1 Exercise protocol

The implemented energy expending protocol varied between studies with Moore et al. (2004), Bozinovski et al. (2009), Nemet et al. (2010) and Tamam et al. (2012) comparing two or more different exercise protocols. The shortest used exercise protocol was by Bellissimo et al. (2007) with a ≤ 12 min low to moderate intensity short-duration walking exercise designed to determine physical fitness based on ventilatory threshold (VT). Tamam et al. (2012) also used a relatively short duration protocol, comparing 15 min of walking exercise at VT and also 15 min walking at 25 % above VT. Fifteen minutes of walking at VT was also used by Bozinovski and colleagues (2009) in their study, as well as a longer duration of 45 min walking at VT.

Moore et al. (2004) and Dodd et al. (2008) both used cycling exercise. Moore et al. (2004) investigated differences following high (75 % peak oxygen uptake) and moderate (50 % peak oxygen uptake) intensity cycling, both set for a duration designed to expend 1.5 MJ of energy (38 ± 5 min and 56 ± 7 min respectively). The protocol utilised by Dodd et al. (2008) was also designed to expend 1.5 MJ of energy from cycling exercise at 75 % peak oxygen uptake. Rumbold et al. (2011) and Nemet et al. (2010) used sport specific activities to expend energy. Rumbold et al. (2011) implemented a 47-min bout of netball exercise based on a netball-specific fitness test. Nemet et al. (2010) compared three types of exercise: aerobic training (typical games play: 50 % team and 50 % running games), resistance training (circuit training using hydraulic weight lifting systems for children) and swimming exercise (swimming games and team sports: water polo) all for durations of 45 min. Choosing an appropriate exercise intervention for paediatric research requires consideration to the suitability of
the duration, intensity and type of the exercise to be implemented. Exercise chosen that is typically habitual to children increases the ecological validity of the findings. All the studies reviewed used exercise protocols appropriate and habitual to children’s activities. In particular, Rumbold et al. (2011) netball protocol and Nemet et al. (2010) swimming and aerobic games play protocol were specifically habitual to the children by their sports focused exercise intervention design. However, they were not performed in the laboratory and so the accuracy of EE was compromised as it was estimated from HR data by Rumbold et al. (2011) and from observations by Nemet et al. (2010). Both the cycling exercise (Moore et al., 2004; Dodd et al., 2008) and the walking exercise (Tamam et al., 2012; Bozinovski et al., 2009; Bellissimo et al., 2007) were performed within the laboratory setting and so EE was calculated using the more accurate method of respiratory gas exchange (indirect calorimetry). For a more detailed overview of methods appropriate for measuring EE in children see chapter 2.1.2.

Due to the nature of the different exercise protocols, the total amount of energy expended differed between the studies. Moore et al. (2004) and Dodd et al. (2008) both used protocols designed to expend 1.5 MJ of energy (over two exercise sessions – morning and afternoon). Similarly, Rumbold et al. (2011) 47 min of netball exercise expended a comparable amount of energy 1.4 ± 0.2 MJ. Much lower amounts of energy were expended in Bellissimo et al. (2007) 12 min protocol where an estimated mean EE of 213 kJ was expended which was similar to Tamam et al. (2012) 15 min walking at VT (255 ± 17 kJ) and 25 % above VT (330 ± 17 kJ) and Bozinovski et al. (2009) short duration (15 min) protocol (boys: 284 ± 25 kJ and girls 242 ± 13 kJ). Bozinovski and colleagues
(2009) long duration protocol however, expended a larger $853 \pm 79$ kJ of energy with the boys and $730 \pm 37$ kJ with the girls. Nemet et al. (2010) reported the EE expressed as per kg bodyweight per session. Calculating EE from mean body mass indicated that the 45 min aerobic exercise session expended approximately 1350 kJ, whilst 45 min of swimming exercise expended ~1074 kJ and 45 min of resistance training exercise ~916 kJ.

Comparisons between these studies are difficult as there is no consistent approach for the implemented exercise, which varied in type, duration and intensity, resulting in different totals of energy expended. Ultimately however, all of these studies manipulated an amount of energy to be expended resulting in an acute energy deficit.

### 3.2.2 Appetite

From the 7 studies reviewed, 6 investigated ratings of appetite along with EI whilst Nemet et al. (2010) assessed EI only. From the review in chapter 2.2, it was suggested that children under 7 y might be unable to comprehend the VAS. This may explain why Nemet et al. (2010) may have chosen not to investigate appetite within their study, as some of their participants were only 6 years old and may not have had the cognitive ability to comprehend an appetite VAS. All 6 studies used the visual analogue scale (VAS) method.

From the 6 studies reported, all assessed appetite ratings for hunger: ‘How hungry are you now?’ (anchored to the left by ‘Very Hungry’ and on the right by ‘Not at all’); fullness: ‘How full do you feel?’ (anchored on the left by ‘Very Full’ and on the right by ‘Very Empty’ and prospective consumption: ‘How much could you eat right now?’ (anchored on the left by ‘Lots and lots’ and on the
right by ‘Nothing’). Bellissimo *et al.* (2007), Bozinovski *et al.* (2009) and Tamam *et al.* (2012) also included desire to eat: ‘How strong is your desire to eat? (anchored on the left by ‘Very Weak’ and the right by ‘Very Strong’). An example of an appetite VAS can be found in Appendix 10.1. All studies measured appetite at the start of the experimental period (baseline), pre and post exercise, and pre and post meal (if applicable), appetite scores were collected over a period that ranged from 2 h to 6 d. Bellissimo *et al.* (2007), Bozinovski *et al.* (2009) and Tamam *et al.* (2012) also chose to capture appetite ratings in the period between cessation of exercise/rest condition and provision of the test meal.

The appetite responses following exercise in children are not consistent. A significant increase was found in some or all of the appetite scores measured following exercise; Tamam *et al.* (2012), Bellissimo *et al.* (2007) and long duration exercise from Bozinovski *et al.* (2009) all showed a ~10 % increase in appetite following exercise; whereas Rumbold *et al.* (2011) found a ~15 % increase following exercise. Significant reductions in some but not all of the appetite ratings were found following exercise by Moore *et al.* (2004) ~30 % reduction following high-intensity exercise and Bozinovski *et al.* (2009) ~7 % reduction following short duration exercise. Finally, Dodd *et al.* (2008) found no change in appetite following cycling exercise at 75% $\dot{V}O_{2\text{max}}$. Such varied findings warrant the need for further research in this area particularly as changes in appetite need to be over ≥ 15 % to have any impact on *ad libitum* EI (Sadoul *et al.*, 2014).
Energy intake was measured following exercise in 6 of the 7 reviewed studies. Bellissimo et al. (2007) did not investigate changes in EI following exercise, instead they recorded changes in appetite and then within the same paper but on a separate testing occasion assessed EI following various preload drinks. From the 7 studies, two methods of measuring EI were used. Rumbold et al. (2011) recorded intake over 5 days through a combination of self-reported weighed food intake diaries and the 24-h recall interview. Whereas, Moore et al. (2004); Dodd et al. (2008); Bozinovski et al. (2009); Bellissimo et al. (2007); Tamam et al. (2012) and Nemet et al. (2010) provided a test meal of known compositions and quantities (metabolic kitchen method). All test meals were provided in a similar format for the latter 6 studies: ad libitum, in excess of requirement, from a choice of foods based on the participants preference and the children were asked to eat until comfortably full. Although the method for provision of the test meal was the same for these 6 studies, the type of test meal offered and at what time point post exercise did however vary. For an in depth review of the methods available to measure EI and their suitability for use with children see chapter 2.1.1. The methods chosen to measure EI by all 7 studies was appropriate based on their study design. Rumbold et al. (2011) used a less accurate method to measure EI (self-reported intake), however due to the long study duration (5 d) this was the most appropriate method available. As the other studies (excluding Dodd et al. 2008) were under 10 h in duration, provision of food via a metabolic kitchen was sustainable for this period of time and therefore accurate measures of EI were achieved.
3.2.4 Type of test meal

Bellissimo et al. (2007), Bozinovski et al. (2009) and Tamam et al. (2012) are part of the same research group and provided their test meal in a similar format: a tray of pizzas. Each tray consisted of two 5 inch diameter pizzas of the child’s 1st choice (choice from pepperoni or three cheese) and one 5 inch diameter pizza from their second choice, cut into four equal pieces. Nemet et al. (2010) provided a buffet lunch that consisted of cooked meats (beef, chicken etc.), cooked accompaniments (potato, rice and vegetables), salad, coleslaw, and two types of dessert. Each time their buffet meal was offered the appearance of the food was altered, although the food items were the same. This was based on a work by Birch (1999) who reviewed the development of food preferences in children and suggested that when choice is offered from a buffet meal, children will make their choices from the first meal and will then make the same choices for subsequent meals as these foods will be familiar to them. As Nemet and colleagues (2010) aim was to also investigate whether exercise altered macronutrient preferences, it was important that habit and familiarity as suggested by Birch (1999) was not a factor in food choice. Nemet et al. (2010) found that macronutrient composition of total intake following exercise significantly altered, with carbohydrate consumption increasing by around 7-15 % and fat consumption decreasing ~7-14 % when compared to the control condition.

To prevent any changes to macronutrient preferences following exercise (as found with Nemet et al. (2010) or any macronutrient satiety hierarchy impacting on EI (Westerterp-Plantenga et al., 2009; Veldhorst et al., 2008), the test meal can be offered in a homogenised macronutrient composition. Moore et al.
(2004) were the only group to offer a homogenised macronutrient composition test meal with 12 % energy provided from protein, 35 % from fat and 53 % from carbohydrate. Items offered for lunch were sandwiches (choice from different fillings), cake and choice of yoghurt or milk-based chocolate/strawberry dessert and for dinner, pasta (choice from a selection), and for dessert a choice from yoghurt, custard or milk-based chocolate/strawberry dessert. Dodd et al. (2008) offered similar items for lunch (sandwiches, yoghurt, cake) to Moore et al. (2004) but also fruit and crisps as this meal was not homogenised presumably due to practicalities of the longer-duration of the study. The dinner meal was similarly not homogenised with choices offered from pizza, pasties, spaghetti bolognaisce, breaded fish/chicken, baked or mashed potatoes, bread and butter, milk based desserts, fruit and yoghurt.

Offering homogenised meals negates macronutrient hierarchy and offers superior energy and macronutrient information. However, this is a costly and time consuming method as the food items are not commercially available and are prepared to order, therefore homogenised meals are only suitable for short duration, controlled studies. An alternative and more simple method for controlling for any changes to macronutrient preferences following exercise would be to offer a test meal without choice (one item), or limited choice (two items akin). This is similar to how Bellissimo et al. (2007), Bozinovski et al. (2009) and Tamam et al. (2012) offered their test meal of pizza. However, limiting choice available is not indicative of a free-living environment.

3.2.5 Time between exercise and provision of the test meal

The time between cessation of the exercise test (or sedentary period) and the provision of the test meal varied between studies. Bozinovski et al. (2009) and
Tamam et al. (2012) implemented the shortest duration with only 30 mins between cessation of exercise and the provision of the test meal. Nemet et al. (2010) offered the meal between 30 and 45 min following exercise, whereas Moore et al. (2004) study design permitted approximately 1 hour. Rumbold et al. (2011) was the only study to allow self-selection of the mealtime; no significant differences were found between the onset of eating between the exercise (2.13 h ± 0.16) and sedentary condition (1.59 h ± 0.05). The duration of approximately 2 h between cessation of exercise and time to eating in Rumbold and colleagues (2011) investigation was the longest duration of all the studies reviewed. It should be noted however that the children from Rumbold et al. (2011) study were within the school environment and therefore potentially may have had restricted availability of eating opportunities based on the structure and scheduling of the school lessons and lunch breaks. Lastly, in the study by Dodd et al. (2008) it was not clear what the time delay was between the test meal and cessation of the exercise because the duration of the exercise bout was individually manipulated to induce the prescribed EE of 0.75 MJ. Their protocol ensured that the exercise started at 1030 h and 1430 h. and that the meal was provided at 1215 h. and 1700 h. Based on a similar protocol used by Moore et al. (2004), to expend 0.75 MJ of energy at 75% peak oxygen uptake, the exercise duration was likely to be around 40 min. With the suggestion that the exercise took ~40 min to expend 0.75 MJ, it was deduced that the duration between exercise and provision of the meal within Dodd et al. (2008) study would have been approximately 1-2 h.

It is therefore unsurprising, based on these methodological differences for the provision and recording of test meals, that the EI responses following exercise
in children were inconsistent. Rumbold et al. (2011) was the only group to find a significant increase (from 16.65 ± 3.48 to 18.63 ± 2.49 MJ) in EI in the 48 h following exercise compared to the sedentary condition. Whilst Moore et al. (2004) (low intensity exercise) and Nemet et al. (2010) (resistance exercise) both found a significant reduction in EI post exercise compared to the sedentary condition (Moore et al., 2004: sedentary condition 5.85 ± 1.3MJ, low intensity condition 5.15 ± 1.4 MJ; Nemet et al. 2010: sedentary condition 2.5 ± 0.3 MJ, resistance exercise 1.8 ± 0.2 MJ). Finally Bozinovski et al. (2009), Dodd et al. (2008), Moore et al. (2004) – high intensity, Nemet et al. (2010) – swimming and aerobic exercise and Tamam et al. (2012) all found no significant changes to EI following exercise. Based on the large age range of participants recruited within the 7 studies (6 to 15 y), the variance between methods for the measuring and/or provision of EI, and whether EI was reported as total daily intake for each eating occasion, it was not deemed appropriate to compare actual EI between studies. With such equivocal findings and methodological differences, further research is warranted in this area within the paediatric literature.

3.2.6 Sex differences

From the 7 papers reviewed, 2 assessed responses in boys only (Bellissimo et al., 2007 and Tamam et al., 2012), 3 in girls only (Moore et al., 2004; Dodd et al., 2008 and Rumbold et al., 2011) and 2 with both sexes (Bozinovski et al., 2009 and Nemet et al., 2010). From the two papers that included both sexes, only Bozinovski et al. (2009) compared the sexes whilst Nemet et al. (2010) combined the findings from both sexes (5 boys and 17 girls). However, due to the limited research within paediatrics between sexes and the obvious sex
differences reported following exercise within the adult literature (see chapter 3.1.2), it is surprising Nemet et al. (2010) combined their findings. A couple of justifications to Nemet and colleagues (2010) decision to combine their findings for both sexes could be, (1) the uneven recruitment of boys to girls (5 boys and 17 girls) and (2) that the age of the children recruited was primarily pre-pubertal (6.2-10.9 y), potentially suggesting that they may have felt sex differences would have less of an impact on pre-pubertal children. Bozinovski et al. (2009) found that boys reported significantly reduced appetite feelings following short but not long duration exercise but no significant changes were found for appetite with the girls. Girls however ate significantly less than the boys, although there were no differences for EI between conditions. Disinhibition in the boys but not girls was also found to positively correlate with EI. With sex differences established within the adult literature and indications they may also be present within paediatrics, it is important that both sexes are investigated with sex specific results reported.

3.2.7 Eating behaviour

From the 7 papers reviewed, only 1 (Bozinovski et al., 2009) investigated eating behaviour, more specifically whether restrained eating behaviour impacted on subsequent EI. Eating behaviour was assessed by the DEBQ (van Strein et al., 1986). Interestingly Bozinovski et al. (2009) used the DEBQ as opposed to the DEBQ-C. No comment was made within the study as to why the DEBQ was chosen over the DEBQ-C other than the children received assistance completing the questionnaire if they had difficulty interpreting the language. Bozinovski et al. (2009) found disinhibition to be positively correlated to food intake in boys (r = 0.54, P=0.047) but not girls (r = -0.039, P=0.89). There was
also a positive association between disinhibition and body weight, fat free mass and VT per kg body weight in the boys but not girls.

Rumbold et al. (2011) did use the DEBQ to ensure participants recruited to their study were unrestrained eaters, although failed to mention why they felt this was an important parameter for their investigation. As suggestions have been made within the adult literature that eating behaviour may impact EI following exercise (see chapter 3.1.3) further investigations assessing eating behaviour are warranted within the paediatric population.

3.2.8 Habitual exercise patterns/fitness levels

Inclusion of participants based on prior physical activity patterns was included in the selection criteria for Rumbold et al. (2011). Participants were recruited from a local netball club where inclusion was based on ‘being trained, which equated to habitually participating in netball-based exercise or competition at least three times per week’ (pp 622). Inclusion criteria for Moore et al. (2004), Bellissimo et al. (2007), Dodd et al. (2008), Bozinovski et al. (2009), Nemet et al. (2010) and Taman et al. (2012) was that the child should be healthy. Bellissimo et al. (2007) was the only study to investigate whether fitness levels as assessed by absolute VT (mL·min⁻¹) had any impact on EI. VT was not associated with EI following the control \( r = 0.36 \), glucose preload drink \( r = 0.41 \) or whey preload drink condition \( r = 0.41 \). However, once VT was expressed on the basis of total body weight \((BW) \) mL·kg BW⁻¹·min⁻¹) there was a positive association with EI following the glucose preload drink \( r = 0.52 \) and the whey preload drink \( r = 0.59 \) although no associations were found for the control condition \( r = 0.31 \). Similarly when VT was expressed on the basis of fat
free mass ((FFM) mL·kg FFM⁻¹·min⁻¹) there was a positive association with EI following the whey preload drink \((r = 0.52)\), but not for the glucose \((r = 0.42)\) or the control condition \((r = 0.31)\).

As comparison studies between habitual and non-habitual exercisers have not been performed within paediatrics, it is unknown whether the improved ability to tolerate energy deficits as seen within the adult population (see chapter 3.1.4) would also be apparent within the paediatric population. However, based on Bellissimo et al. (2007) findings, there appears to be significant correlations between fitness and improved EI awareness \((r \sim 0.50, p<0.05)\). As current literature has not accounted for individual fitness levels between participants, this may elude towards why differences were found for EI between studies. Further research is warranted within this area and it is suggested that fitness levels are taken into consideration for any future work.

### 3.2.9 Body size

As with the adult literature, body size appears to also be a confounding variable in children that may alter the EI and appetite responses to an imposed exercise bout. As normal weight children were the focus of this thesis, the findings from the overweight and obese literature shall be reviewed in brief. There are presently to the best of the authors' knowledge, 3 studies that have directly compared normal weight to overweight/obese children within their study design (Dodd et al., 2008; Nemet et al., 2010 and Tamam et al., 2012). Dodd et al., (2008) observed a change in appetite (decrease in fullness and increase in hunger) following cycling exercise at 75 % \(\text{VO}_2\text{max}\) in overweight girls, whilst there were no changes to appetite following the same exercise bout in normal
weight girls. Although there was a change in appetite for the overweight girls, this did not result in a change in EI between the two conditions, neither were any changes to EI observed between the exercise and rest condition for the normal weight group. Similarly, Tamam et al., (2012) also observed an increase in hunger, prospective consumption and desire to eat and a decrease in fullness following 15 min walking at VT compared to control. However, this change in appetite was observed in both the normal weight and overweight/obese groups. Similarly to Dodd et al., (2008), Tamam et al., (2012) observed no change to EI following the exercise bout in either the normal weight or overweight/obese group. Conversely to both Dodd et al., (2008) and Tamam et al., (2012), Nemet et al., (2012) found the obese children would significantly increase their EI compared to a control condition, following 45 min of swimming exercise and increase their EI but not significantly following aerobic and resistance type exercise. This is in contrast to the normal weight children who significantly decreased their EI following resistance type exercise compared to a control condition, and decreased their EI but not significantly following the swimming and aerobic type exercise. There have also been 3 studies that have recruited just obese children (Thivel et al., 2011a; 2011b and 2012), however their findings for the purpose of this section are limited without normal weight comparators. All 3 studies found a significant reduction in EI compared to the sedentary condition following ~30 min of cycling exercise at 70-75 % $\dot{V}O_{2\text{max}}$, whilst they all found no significant changes to appetite. These findings allude to body size as a confounding variable, however further research is required where both normal weight and overweight/obese children are recruited to exercise matched studies so that direct comparisons can be made.
3.2.10 Summary

From the reviewed publications it can be concluded that the findings related to both EI and appetite post-exercise are inconsistent. Differences in methodological and participant characteristics are significant between these studies, which may explain why the findings are inconclusive. Further investigations surrounding how both the protocol (type of exercise, provision and type of test meal) of the study and the characteristics of the participant (sex, habitual PA, eating behaviours) impact EI and appetite following an imposed bout of EE are warranted within paediatric studies.
3.3 Current Findings in fMRI

Food selection and size of intake can be influenced by pleasant and palatable food stimuli. This influence can override innate homeostatic controls inhibiting weight loss through increased EI and may contribute to weight gain (Yeomans, Blundell, & Leshem, 2004). Increased food intakes are associated with a greater response of the reward circuitry within the brain following food and/or food cues (Burger & Stice, 2011). Both positron emission tomography (PET) and fMRI are imaging methods able to measure activity of the brain reward systems. Food stimuli can present through three sensory modalities: gustatory, olfactory and visual, all of which may influence eating behaviour. Brain imaging studies address the modalities of sensory inputs, determine eating behaviour, food-related cortical processes and whether they differ between conditions or participants.

Whether through the media, on screens, in print or when others are eating, visual food cues are continually presented to individuals. These visual food stimuli can trigger a wide range of physiological, emotional and cognitive responses, e.g., memory retrieval (previous learning experiences of food) or hedonic evaluation and inhibitory mechanisms governed by self-regulation (Burger & Stice, 2011; Pelchat, Johnson, Chan, Valdez, & Ragland, 2004). Visual food stimuli activate a diverging network of brain regions. However, regions of activation are not always in accordance with each other when comparing studies. These inconsistencies have been attributed to a combination of participant characteristic differences, study designs, tasks and stimuli differences (Van der Laan, De Ridder, Viergever, & Smeets, 2011; Uher, Treasure, Heining, Brammer, & Campbell, 2006). The following chapter will
discuss some of the brain activation findings following visual food stimuli comparing participant characteristic differences (sex, dietary restraint, age (children) and body weight) and methodological differences (following exercise and rest condition, between a fasted and fed condition). Figure 3.2 displays common regions of the brain.

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Figure 3.2 - Summary of brain regions (taken from http://brainanatomy.tk/tag/brain-anatomy-2014)

3.3.1 Sex differences

Sex differences have been demonstrated to influence both the regulation of eating behaviour and food preferences (Woods, Gotoh, & Clegg, 2003). Del Parigi et al. (2002) performed a sex comparison (22 males and 22 females) study using the PET technique to measure neurological changes in a fasted (36 h) or fed (liquid test meal delivered through a tube) condition. Males in the fasted condition had greater brain activation in regions mainly associated with emotion compared to females (dorsolateral prefrontal cortex, middle gyrus, posterior cingulate and parahippocampal gyrus areas). In the fed condition, the females had greater activation in regions associated with sensorial association and behavioural planning compared to males (occipito-temporal cortex, angular gyrus, precuneus and dorsolateral prefrontal cortex). The males when fed had greater activation when compared to females in an area associated with the processing of association between stimuli and response (ventromedial prefrontal cortex). Uher et al. (2006) conducted an fMRI study comparing brain
responses in 10 females and 8 males following visual stimuli of 20 easy to recognise, pleasant and appetising foods (e.g. roast chicken, hamburger, chocolate cake, strawberries) and 20 non-food items, matched to the food images on visual complexity and colour composition (e.g. armchair, brushes, car, flower). Females showed a stronger response to the food-related visual stimuli in the fusiform gyrus bilaterally, a region associated with sensory processing. Uher et al. (2006) suggested that the increased reactivity to external food-related stimuli in females should be explored further as it may explain the increase in female susceptibility to eating disorders (Hoek, 2006; Striegel-Moore & Bulik, 2007).

The difference in brain activations to food images of high energy (cheese burger, hot dogs, ice cream, cake); low energy (mixed salads, vegetables, whole-grain cereals) and control images (shrubs, rocks, flowers, bricks, leaves) in 8 males (46.5 ± 5.4 y) and 8 females (48.0 ± 5.7 y) was investigated by Killgore and Yurgelun-Todd (2010). The females when compared to males, showed significant greater activation to the energy-rich foods within regions associated with high-level decision making, selecting and planning (dorsolateral prefrontal cortex), response inhibition (inferior lateral orbitofrontal cortex), self-reflection, self-referential thoughts and imagining future personal events (ventromedial/orbitofrontal cortex and posterior/middle cingulate gyrus) and feelings of hunger and evaluation of current need states (insula). The males in response to viewing food images conversely activated the amygdala, a region associated with determining the appetitive value or attractiveness of food. It appears that females in response to viewing high-energy foods activate cortical regions associated with behavioural control and self-referential cognition moreso than males. Killgore and Yurgelun-Todd (2010) speculated that greater
activation in the females for regions associated with decision-making, inhibitory and self-referential cognitive systems, when confronted with images of high versus low-energy foods, may be associated with the higher prevalence rates among females for eating disorders (Hoek, 2006; Striegel-Moore & Bulik, 2007). However, this theory would need further exploration.

In summary, the findings from the studies presented suggest that brain activation data in response to visual food stimuli should be reported sex specifically, as sex differences for regions of significant activation are apparent.

3.3.2 Dietary restraint

Individuals with high dietary restraint scores are more likely to present with elevated weight (Laessle, Tuschl, Kotthaus, & Prike, 1989; Nederkoorn & Jansen, 2002; Roefs, Herman, MacLeod, Smulders, & Jansen, 2005) and an increased risk for future weight gain (Klesges, Isbell, & Klesges, 1992; Stice, Cameron, Killen, Hayward, & Taylor, 1999; Stice, Presnell, Shaw, & Rohde, 2005; Tanofsky-Kraff et al., 2007) than unrestrained individuals. Restrained eaters have also been shown to present with a greater salivary response to the sight and smell of food and increased cravings for palatable foods than unrestrained eaters (Burger & Stice, 2011). The first published study examining dietary restraint and brain activation in response to food stimuli was performed using PET by Volkow et al. (2003). Volkow et al. (2003) correlated the restrained eating behaviour scores in 8 males and 2 females (35 ± 8 y) to brain dopamine levels following the presentation of both smell and taste of food. Dopamine is a neurotransmitter that has been associated with the hedonic and non-hedonic factors underlying motivation for food intake (Volkow et al., 2003). Increased dietary restraint was positively correlated with an increase in
dopamine release in the dorsal striatum. This was the first study to indicate that the dorsal striatum was involved in dietary restraint and the regulation of eating behaviour.

Coletta et al. (2009) went on to conduct an fMRI study in 9 female restrained and 10 female unrestrained eaters. Following an 8 h fast (0800 h to 1600h), participants were presented with pictures of highly palatable foods (French fries, pizza, chocolate chip cookies, ice cream etc.); medium palatable foods (apple, carrots, baked potato, slice of bread etc.) and neutral stimuli objects (tree, car, rock, stapler etc.). Participants were then given a liquid meal (2.09 MJ), waited 45 min for the meal to be absorbed before having a second scan, viewing the same images. Significant activations in response to highly palatable foods were observed in the fasted unrestrained eaters in areas of the brain associated with hunger, expectation of reward and reinforcement. Restrained eaters when fasted showed significant activation in the cerebella lingual, an area implicated in modulating lower level processing of food stimuli. When fed, the restrained eaters in response to highly palatable foods had an increase in activation in the orbitofrontal cortex, (an area associated with hunger, desire for food and expectation of a reward), the left dorsolateral prefrontal cortex (implicated in reward, decision making and monitoring of behavioural consequences), and the left insular cortex (associated with desire for food). Fed unrestrained eaters conversely showed greater activation in the precuneus and parahippocampal gyrus, areas associated with memory. This data indicated significant brain activation differences occur between female restrained and unrestrained eaters in both a fed and fasted condition.

Finally, Burger and Stice (2011) investigated how visual food stimuli following either a food taste (chocolate milkshake) or no taste altered brain activations in
29 adolescent girls 14-17 y. They also investigated how highly palatable and unpalatable food image stimuli altered brain activations. All measures were correlated against dietary restraint scores. The girls with higher dietary restraint scores showed hyper response from food stimuli in regions associated with food reward (orbitofrontal cortex and dorsolateral prefrontal cortex) compared to those with lower restraint scores. These findings match those reported by Coletta et al. (2009) where the same brain regions were activated in response to appetising food pictures in highly restrained individuals. It was proposed by Kringelbach (2005) that these regions play a role in encoding food liking and other types of rewards. Burger and Stice (2011) went on to suggest that increased dietary restraint may be associated with an elevated response of brain reward circuitry following food intake, anticipated intake, or food cues which may increase the risk for overeating or binge eating.

3.3.3 Children and adolescents

The maturation of the brain (or ‘rewiring’) occurs through childhood from as young as 10 years until 25 years, with the rate of maturation influenced by a multitude of factors (Figure 3.3, Arian et al., 2013). Changes in both the morphology and function of the human brain advances through adolescence (Giedd et al., 1999). Therefore, understanding how the brain responds to stimuli at different stages throughout maturation is important.

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In addition to the study by Burger and Stice (2011) in adolescent female restrained eaters (14-17 y), there have only been three other studies (Holsen et al., 2005; Leidy, Lepping, Savage, & Harris, 2011; Davids et al., 2009) who have looked at brain activation in response to food stimuli in children. However, these latter studies have recruited children over a large age range, which is surprising considering the changes in morphology and function within the brain throughout maturation as previously stated.

Holsen et al. (2005) were the first to study brain activation in response to food cues in children. Five girls and four boys aged 10-17 years were scanned in a fasted state (4 h post meal) and after consumption of a 2.09 MJ meal. Images of foods, animals and blurred images were presented to the participants throughout the functional scan. The children in the fasted condition showed increased activations to visual food stimuli in regions associated with food motivation (amygdala, medial frontal/orbitofrontal cortex), and also the insula, where the primary taste cortex is located. There were no significant activations in the fed condition, suggesting when hungry, images of foods evoke an increase in activation for food and taste motivating brain regions in children, whereas when fasted no such activation differences were observed. Brain activation in 10 overweight to obese 13-18 y girls was investigated by Leidy et al. (2011) looking at changes in brain activity in 3 conditions: (1) fasted, (2) on day 7 following a week of consuming a normal protein breakfast (18 g per meal) (3) on day 7 following a week of consuming a high protein breakfast (50 g per meal). The addition of a high protein breakfast condition was based on
previous work by Leidy and Racki (2010), where reductions in EI and physiological markers of appetite were observed following a high protein intake. Images of foods, non-foods (animals) and blurred baseline images were presented. Being fed resulted in reductions in brain activation responses to food stimuli in regions associated with hedonic, reward-driven eating (hippocampus, parahippocampus and amygdala) and reward (anterior cingulate). Following increased dietary protein a reduction in the activation of the anterior insula, a region associated with gustatory processing, reward, desire and cravings and the middle prefrontal cortex, a region associated with food motivation, were observed compared to the normal protein intake condition. These findings suggest that the addition of dietary protein to the breakfast meal may help reduce reward-driven eating behaviours in obese adolescent females.

A comparison of brain activation responses to food images between lean and overweight children was carried out by Davids et al. (2009). They investigated the response to visual food stimuli in 22 overweight/obese children (BMI 29.44 ±3.87 kg/m²) and 22 normal-weight children (BMI 19.70 ±2.50 kg/m²) aged 9-18 y. The obese children showed higher activations of the dorsolateral prefrontal cortex in response to the food pictures compared to the normal weight children. The dorsolateral prefrontal cortex is a region associated with avoidance, indicating the obese children already present with strong inhibitions to food-related reward systems and prevention of overeating. Activation in the dorsolateral prefrontal cortex was also negatively correlated with self-esteem (assessed from a questionnaire). Normal weight children in response to food stimuli showed increased activations in regions associated with food reward (caudate) and controlling feeding behaviour (hippocampus). These findings
suggest that within the paediatric population, activation differences for regions of the brain will differ dependent on body size.

### 3.3.4 Body size (obese v lean)

Body size differences have been recognised as a key variable for changes to brain activations in response to food stimuli. However, as body size comparatives were not investigated within the research presented in this thesis, this area will be only briefly reviewed.

In addition to the body size comparative study by Davids et al. (2009) in children (see chapter 3.3.3), Rothemund et al. (2007) and Scharmüller, Übel, Ebnar, and Schienle (2012) conducted body size comparative studies in adults. Rothemund et al. (2007) found that as an individuals’ BMI increased, so would the activations in the following areas, the dorsal striatum (habit learning), anterior insula (taste information), posterior cingulate (memory functions), postcentral and lateral orbitofrontal cortex (motivation), (0.50 < r > 0.76, P<0.05).

Scharmüller et al. (2012) examined neuronal activity in 12 obese females (26.6 ± 4.5 y) and 14 lean females (25.6 ± 6.7 y) to pictures of high-energy foods and non-food items. Obese individuals showed greater activation in the insula, lateral and medial orbitofrontal cortex than the lean individuals in response to the food pictures when compared to the non-food pictures. The insula and medial orbitofrontal cortex were suggested as regions associated with food reward processing (Scharmüller et al., 2012). The insula has also been suggested to have a central role in food processing, particularly in obesity (Rothemund et al., 2007; Schienle, Schäfer, Hermann, & Vaitl, 2009; Weygandt, Schaefer, Schienle, & Haynes, 2012).

As body size appears to significantly alter the regions of the brain that are
activated in response to food stimuli, future study designs should consider the physical characteristics of the individuals recruited to studies. Future research investigations into body size should also aim to conduct longitudinal studies in order to deduce whether the neurological differences between lean and obese individuals are because the individuals are obese, or whether they become obese because of these differences.

3.3.5 Exercise

There have been a few investigations into how exercise both in the acute phase (Evero, Hackett, Clark, Phelan, & Hagobian, 2012) and over the longer-term (Cornier, Melanson, Salzber, Bechtell, & Tregellas, 2012) impact on brain activations. As a whole, there is a paucity of literature surrounding food stimuli and brain activations in children. For this reason it was decided not to include exercise as a variable within the protocol of the study reported in chapter 8. However, using an exercise intervention would be the next step for this area of research. For this reason, the findings in adults following exercise will only be briefly discussed.

Brain activations in response to food images following either 60 min of rest or 60 min of high intensity cycling exercise ($83 \pm 1 \% \text{HR}_{\text{max}}$) were investigated in adults by Evero et al. (2012). Following the exercise or rest the participants were presented with control images (trees, shrubs, flowers etc), images of low-energy foods (fruits, vegetables, whole-grain cereal etc) and images of high-energy foods (cheeseburgers, French fries, ice cream sundaes, chocolate chip cookies, etc). Although both males ($n=17$) and females ($n=13$) were recruited, their results were not reported separately, a sizable limitation to the analysis from this study since sex differences are so evident (chapter 3.3.1). The acute
bout of exercise reduced neuronal responses in the brain regions associated with reduced pleasure for food, reduced incentive motivation to eat and reduced anticipation and consumption of food (the insula, putamen, and rolandic operculum). Suppression in food reward following an acute bout of exercise was suggested by Evero et al. (2012) to be in accordance with the model of suppressed EI following acute bouts of high intensity exercise.

The impact of a longer-term 6-month progressive exercise intervention (5 d/week supervised) on brain activation differences in response to visual food stimuli was conducted by Cornier et al. (2012) in 12 overweight/obese adults (BMI 33 ± 4 kg/m²; 5 female, 7 male). Images of foods with a high-hedonic value, foods of a neutral hedonic value and neutral non-food related objects were presented. The chronic exercise intervention was associated with a reduction in neuronal responses to food stimuli in regions associated with food intake regulation (the posterior attention network and insula). Significant positive correlations were also observed between the change in fat mass following the exercise intervention and neuronal activity within the insular ($r^2 = 0.61$, $P=0.003$). These findings indicate that there are significant changes to the neuronal response in regions associated with food intake regulation following a long-term exercise intervention. This suggests that changes in brain activation may be responsible for alterations in EI and/or appetite following both acute bouts of exercise and chronic exercise interventions. Further research is required to establish whether similar changes are observed within the paediatric population.

3.3.6 Fasted v fed
In addition to the above studies, Uher et al. (2006) and Goldstone et al. (2009) have also studied brain activation differences between fasted and fed states. A fed state (satiated), has been described as the absence of hunger and will influence meal termination, whilst a fasted state (hungry), relates to food-seeking behaviour and meal initiation (Uher et al., 2006). Uher et al. (2006) found the fasted participants rated the visual food stimuli as significantly more pleasant (increase by 1 on a scale of 1-5) compared to the satiated condition while the visual non-food stimuli were rated as neutral in both conditions. Hunger and satiety were found to modulate the processing of food-related stimuli in the higher-order visual areas of the inferior occipito-temporal cortex. Uher et al. (2006) suggested that their findings, in corroboration with those of Gottfried, O'Doherty, and Dolan (2003); LaBer et al., (2001) and Small, Zatorre, Dagher, Evans and Jones-Gotman (2001), implicated the higher-order sensory cortical areas in the conceptualisation of motivated behaviour and not just recognition.

The impact of a macronutrient and energy controlled breakfast was compared to an overnight fasted condition for brain response differences in 10 males and 10 females (19-35 y) by Goldstone et al. (2009). Participants were presented images of high-energy foods (burgers, cakes, chocolate); low-energy foods (salads, fruits, vegetables, fish); non-food-related household objects (furniture, clothing, and electrical equipment) and Gaussian blurred images of the high-energy foods, low-energy foods and object pictures. Fasting increased activations in the ventral striatum, amygdala anterior insula and medial and lateral orbitofrontal cortex with activation bias for high-energy food images over the low-energy images. These observations show an interaction between homeostatic and hedonic aspects of feeding behaviour, with fasting biasing
brain reward systems towards palatable, high-energy foods. Therefore any future study aiming to investigate neurological changes in response to food stimuli should consider controlling EI in the 12-24 h preceding the fMRI scan.

3.3.7 Summary

It is clear that a multitude of variables including age, sex, dietary restraint and body size can modulate brain activation following visual food stimuli. Therefore, future research should aim wherever possible not to group these variables together i.e. report the sexes separately, check for dietary restraint, and control for body size. In particular, children’s literature should aim to control the age range of participants more stringently due to maturational brain differences. Lastly, as protocol differences (fed v fasted or high v low energy) have also been shown, consideration to the research question and consequential study design should be carefully considered. For example, food intake should be controlled on the days of investigation and the food stimuli chosen should also be manipulated appropriately.
3.4 Overall Aims and Objectives of the Thesis

Aim: to investigate the effects of exercise on appetite and EI in children, and to establish any mechanisms that may elucidate any changes observed.

Objectives:

1. To investigate whether habitually active adolescent girls increase their EI to replace the EE following an imposed bout of exercise and if so, how accurate the increase in EI is in relation to compensate for the EE.
2. To develop a sustainable maximal sprint interval exercise protocol for adolescent boys and girls and to investigate whether maximal sprint interval exercise alters EI and/or appetite in boys and girls.
3. To explore any sex differences for EI and appetite following an imposed bout of exercise (both moderate intensity exercise and maximal sprint intensity exercise).
4. Examine the effects of mid-morning snacks on subsequent appetite and EI and how the addition of a mid-morning snack differs to an imposed bout of energy-matched exercise.
5. To investigate the awareness of the energy expended following participation in habitual sporting activities and whether this could be conceptualised into quantifiable amounts of energy contained within food and drink.
6. To investigate whether neurological changes mechanistically underpin differing response to food stimuli between the sexes and in those with differing dietary restraint scores.
7. To determine if eating behaviours as assessed by the DEBQ-C correlate to EI in both the exercise and sedentary conditions.
4 The effect of 1 h moderate intensity exercise on energy intake and appetite sensations in habitually active 12-13 y girls

4.1 Abstract

Increased habitual activity in adults has been associated with an increased accuracy to acutely alter EI in response to both a pre load meal and an imposed exercise bout. Whether habitually active adolescent girls are equally as able to increase their EI in compensation for a 60 min bout of moderate walking exercise was investigated.

Acute changes in EI (ad libitum lunch) and appetite (hunger, fullness and prospective consumption, measured by VAS) were recorded in 17 habitually active 12-13 year old girls, following a sedentary condition (SED) and an exercise condition (EX).

EI was not significantly different between conditions (P>0.05). Hunger and prospective consumption increased significantly over time (P<0.001), whilst fullness decreased significantly over time (P<0.001); however, there were no significant differences between conditions (P>0.05). Percent energy compensation was calculated where 100 % compensation suggests EI was increased to match the energy deficit of the exercise. Mean compensation was 17 %, however the range of compensation was from -160 % to 166 %.

An imposed bout of moderate intensity exercise did not significantly alter acute EI or appetite in habitually active girls. The girls were unable to accurately increase their intake to compensate for the energy deficit created by the exercise. Changes in acute EI following a bout of exercise are recommended to be assessed on an individual basis, as the difference between participants is large.
4.2 Introduction

Maintaining a normal body weight and energy balance is vital to sustain good health, prevent disease and prolong life. Adolescent females commonly increase their physical activity as a method to improve or maintain body image (Jankauskiene & Kardelis, 2005), a group commonly associated with body image dissatisfaction (Laus, Costa, & Almeida, 2011). With levels of overweight and obesity in adolescents around 33% (Health Survey for England 2012), understanding the drivers and barriers to maintaining energy balance in adolescent females is of key importance.

Previous research investigating acute changes in intake between habitual and non-habitual exercisers have only been performed in adults. Short-term food regulation in response to a preload eating occasion has been shown to be more accurate in adult habitual exercisers when compared to non-habitual exercisers (Long & Morgan, 2002; Van Wallegehen et al., 2007). Highly active males were found to increase their intake of a test meal compared to moderately active males (Harrington et al., 2013), suggesting that habitual exercisers are more aware of their energy requirements then non-habitual exercisers. In the paediatric population, Bellissimo et al. (2007) correlated fitness levels (VT) to EI following a preload drink. VT was not associated with EI following the control, glucose or whey preload drink conditions. However, once VT was expressed on the basis of body weight (VT mL·kg BW^{-1}·min^{-1}) there was a positive correlation with EI compensation for both the glucose (r = 0.52) and whey preload drink (r = 0.59).
Whether adolescent female habitual exercisers have the same increased awareness surrounding their EI to that of adult males, and are therefore more able to increase their intake to match and compensate for an imposed bout of exercise, remains to be studied.

Therefore, the aim of the present study was to investigate whether moderate intensity exercise evokes acute changes to appetite and/or EI with 12-13 y old habitually active females. Of particular interest is whether the adolescent females increase their intake to replace the energy expended by the exercise and how accurate is the change (if apparent) in EI. The hypotheses are (1) moderate intensity exercise will increase acute appetite and EI as the girls aim to replace the energy expended from the exercise and (2) the increase in EI will be accurately matched (within 10 %) to the energy deficit created by the imposed exercise bout.

4.3 Methods

4.3.1 Design

Acute appetite responses and EI at a lunchtime meal were compared using a within subjects design in habitually active adolescent girls in a sedentary (SED) and moderate-intensity exercise condition (EX). Participants were randomly assigned to either the SED or EX condition in a counterbalanced order.

4.3.2 Participants

Seventeen habitually active 12 – 13 y old girls were recruited from a secondary school in the South West of England. A brief medical history questionnaire was
used to exclude from the study children with a history of diabetes or other metabolic disorders known to affect intermediary metabolism. 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. Power calculations suggest a sample size over 10 would be suitable for this research, based on previous EI literature (Dodd et al 2008): mu0: 4.57; mu1: 5.92; sigma: 1.06; alpha: 0.05 desired power: 0.80.

4.3.3 Measurement of activity status

The participants were only asked to volunteer if they regularly played sport either on the school teams or outside of school, a criterion confirmed by their P.E. teachers. A second verification of habitually physical activity (PA) levels was through accelerometer data collection. Participants were required to wear an accelerometer (ActiGraph GT1M LLC, Pensacola, FL) for seven consecutive days, only removing for water-based activities. A minimum of 3 complete days of data recording was required. Days were discounted if 10 h wear time was not met or where significant durations of non-wear time without recorded reason were shown (data missing for >1 h) (Ward, Evenson, Vaughn, Rodgers, & Troiano, 2005). A 2 s epoch was used to capture transitions in activity typical in children. The raw data was converted and analysed using the Actilife 6 software (ActiGraft, Pensacola, FL). Non-wear time was removed and using the cut-offs for moderate to vigour physical activity (MVPA) by Trost, Ward, Moorehead, Watson, Riner and Burke (1998), time spent in MVPA was calculated and averaged for by the number of days of complete wear time (minimum 3 days). Data from two of the girls were not included in the analysis since they were competitive swimmers and had to remove their accelerometers whilst training.
Providing the children met more than 60 min of MVPA (current PA guidelines for children, Department of Health 2011), they were assumed to be habitually active. All the girls recruited met this criterion, with average MVPA being 102 ± 23 min per day.

### 4.3.4 Experimental design

Participants were assigned into pairs to attend the research centre for three visits. Each day was separated by a minimum of a week to a maximum of three weeks. The three visits consisted of an initial visit for familiarisation and preliminary measurements followed in a counterbalanced design the SED or EX condition. Where possible, testing occurred on the same day of the week.

### 4.3.5 Preliminary visit

On day one, participants were brought to the laboratory for anthropometric measurements, a steady state exercise test, a \( \dot{V}O_{2\text{peak}} \) test and to familiarise themselves with the testing procedures and the laboratory environment. Stature and sitting stature were measured to the nearest 0.01 m using a stadiometer (SEC-225, Seca, Hamburg, Germany). Weight was measured to the nearest 0.1 kg using digital scales sensitive to 100 g (Hampel XWM-150K, Hampel Electronics Co. Taiwan) whilst the subjects were wearing light sports clothing and no shoes. Body density was estimated by air displacement plethysmography (BODPOD, Life measurements instruments, Concord USA) in accordance with the methodology of Dempster and Aitkins (1995). Maturation was also estimated from peak height velocity using Mirwald and colleagues (Mirwald, Baxter-Jones, Bailey, & Beunen, 2002) equations. Table 4.1 represents a summary of the basic physical and physiological characteristics of the participants.
Following familiarisation to running at various speeds on a motorised treadmill (Woodway PPS 55 Sport slat-belt treadmill, Woodway GmbH, Weil am Rhein, Germany) and after 10 min rest, a steady state exercise test was performed and used to calculate gaseous exchange threshold (GET). GET was used to set the exercise intensity (speed of the treadmill) for the EX condition at 80 % of GET. The steady state exercise test comprised of walking/running at 7 km·h\(^{-1}\) at a 1 % gradient for 3 minutes. After each 3-minute bout the speed was increased by 1 km·h\(^{-1}\) until the last bout of either 9 or 10 km·h\(^{-1}\) was completed, depending on ability. Expired air samples were collected throughout (Cortex MetaLyzer 3B, Germany and Metasoft v2.1 software), together with heart rate (HR) and ratings of perceived exertion (RPE) (Yelling, Lamb, & Swaine, 2002), which were recorded over the last 10 s of each minute.

Following a rest period of > 20 min, the adolescents were asked to complete a \(\dot{\text{V}}\text{O}_2\text{peak}\) test. At a speed between 8-10 km·h\(^{-1}\) with a 1 % gradient, the participants began running. At the end of each minute, the treadmill gradient was raised by 1 % until the participants reached volitional exhaustion. Expired air samples were collected throughout together with HR and RPE, which were recorded over the last 10 s of each minute. Participants were actively encouraged to continue until volitional exhaustion. Volitional exhaustion was considered if, in addition to subjective indicators of intense effort (RPE > 9, facial flushing, sweating, discomfort), RER reached a value > 1.05 and maximal HR was ≥ 95 % of age-predicted maximum (220 - chronological age). All participants satisfied these criteria. \(\dot{\text{V}}\text{O}_2\text{peak}\) was taken as the absolute highest value over a 10 second average before cessation of the exercise test.
Lastly for the preliminary day, the girls were interviewed about their food preferences, intolerances or allergies in order to design test meals that were acceptable to them. An eating behaviour assessment was carried out for each participant using the DEBQ-C (van Strien & Oosterveld, 2008).

4.3.6 Testing days

Participants arrived at the laboratory at 0830 h following a 12 h overnight fast, which was verbally confirmed upon arrival. Participants consumed an ad libitum breakfast by 0900 h, where intake was weighed and recorded for replication for the subsequent experimental visit. As breakfast intake remained a constant, it was not included in any of the EI calculations. Participants remained sedentary in the laboratory before and following the exercise and throughout the SED condition by reading, completing homework, watching DVDs or playing computer games.

4.3.7 Exercise condition

The exercise started 2 h after breakfast (1100 h), where all participants completed three 20 min bouts of continuous exercise on a motorised treadmill at 80 % GET. A rest period of 5 – 10 min was offered along with 250 mL of water between the bouts. Any water remaining was measured and recorded. Expired air samples were collected over the last 20 min bout to verify exercise intensity and calculate EE.

4.3.8 Sedentary condition

As with the exercise condition, participants performed sedentary activities following breakfast. Water provisions mimicked the exercise condition with three cups of 250 mL of water being offered at 1120 h, 1150 h and 1220 h. Any water remaining was measured and recorded. At 1230 h resting EE was measured
through the collection of three 5 min expired air samples. Participants were asked to sit quietly whilst the expired air was collected in a 100 L Douglas bag (Cranlea and Co) before analysis for volume and oxygen/carbon dioxide concentrations (dry gas meter, Harvard and paramagnetic oxygen and infrared carbon dioxide analyser, series 1400, Servomex Ltd.)

4.3.9 Lunch provisions

The lunchtime meal was offered *ad libitum*, at 1330 h, (1 h after exercise had concluded). The test meals were prepared by one researcher and designed to mimic the participants’ usual intake on a normal school day. Lunch consisted of sandwiches (a choice from: cheese and margarine; sausage, margarine and ketchup; chocolate spread; jam and margarine or peanut butter and margarine) and a plain sponge cake with vanilla frosting. The same selected choice of sandwich was provided for each test visit. Each food item had a homogenised macronutrient composition of 53 % energy from carbohydrate, 35 % energy from fat and 12 % energy from protein to prevent any effects of macronutrient satiety hierarchy (Westerterp-Plantenga *et al.*, 2009; Veldhorst *et al.*, 2008) and to counteract changes in macronutrient preferences following exercise (Nemet *et al.*, 2010). The macronutrient composition chosen for the food items was similar to the average macronutrient requirements for adolescents of this age group (Department of Health, 1991). As the meals were offered *ad libitum*, volumes of food placed on the plate were offered in excess of requirement and were similar to the daily estimated average requirements of energy for adolescent girls of this age (8 MJ; Department for Health 1991). Four MJ of sandwiches and 4 MJ of cake were placed on each plate in bite-sized pieces to disguise the quantity being offered. Such large amounts of food were offered to encourage the adolescents to eat until they felt comfortably full and not when
the plate was empty. The adolescents were informed that they were not expected to finish the plates of food, however more could be provided if requested. Food intake was measured by subtracting the initial plate weight from the final plate weight to the nearest 1 g (Air Super Slim Kitchen Scales, Salter, UK) out of sight of the adolescents. Adolescents were separated from one another for the lunch meal and constantly observed by the researcher who sat between the two rooms; interactions with the researcher were kept to a minimum. Participants had until 1400 h to finish their meal.

### 4.3.10 Appetite ratings

Appetite ratings were taken on both conditions after breakfast (0930 h), mid-morning (1045 h), before lunch (1230 h) and after lunch (1400 h). Subjects were asked to rate their hunger, fullness and desire to eat (prospective consumption) using VAS on 100 mm lines as described in chapter 3.2.2. VAS were chosen to measure appetite as they are the most commonly used tool available for use with children (Bellissimo et al. 2007; Bozinovski et al. 2009; Dodd et al., 2008; Moore et al., 2004; Rumbold et al., 2011 and Tamam et al. 2012). VAS have also been validated as a reliable and reproducible tool for measuring pain in children (Shields et al., 2003; McGrath et al., 1996).

<table>
<thead>
<tr>
<th>EX</th>
<th>Break fast</th>
<th></th>
<th></th>
<th></th>
<th>Lunch</th>
</tr>
</thead>
<tbody>
<tr>
<td>SED</td>
<td>Break fast</td>
<td></td>
<td></td>
<td></td>
<td>Lunch</td>
</tr>
<tr>
<td>Time</td>
<td>0830</td>
<td>0900</td>
<td>0930</td>
<td>1000</td>
<td>1030</td>
</tr>
<tr>
<td>VAS</td>
<td></td>
<td></td>
<td>*</td>
<td>*</td>
<td></td>
</tr>
</tbody>
</table>

![Figure 4.1](image.png)

**Figure 4.1 - A schematic of the time line for both the sedentary (SED) and exercise (EX) condition**
4.3.11 Calculation of energy expenditure

EE from both the EX and SED condition were calculated using the equations by Péronnet and Massicotte (1991). An average of $\dot{V}O_2$ and $\dot{V}CO_2$ over the 20 min exercise bout was calculated for the EX condition and multiplied to generate the total EE from the 60 min bout. Similarly an average of $\dot{V}O_2$ and $\dot{V}CO_2$ from the Douglas bag recordings were used for calculating resting EE and multiplied to give resting EE over 60 min.

4.3.11.1 Energy compensation calculations

Percent energy compensation was calculated as below:

$$\frac{(EI_{EX} - EI_{SED})}{(EE_{EX} - EE_{Rest})}\times 100\%$$

This is based on the equation developed by Johnson and Birch (1994). Positive compensation indicates a greater intake in the EX condition and a negative compensation indicates a lower intake in the EX condition when compared to the SED condition. A value of 100 % would suggest that EI had increased to match the energy cost of the EX session.

4.3.12 Statistics

Results are presented as mean ± SD unless otherwise stated. EI, EE and water consumption were compared between conditions using Student’s paired t-tests. Appetite scores from the VAS were compared between condition and over time using a repeated measures ANOVA. Significant differences within the ANOVAs were investigated using post hoc Bonferroni corrected pairwise comparisons. A Greenhouse-Geisser correction factor was applied if Mauchly’s test of sphericity was violated. Pearson’s correlations were calculated between percentage
energy compensation and both eating behaviours (emotional, external and restrained eating) and anthropometric data (stature, weight, % body fat and aerobic capacity ($\dot{V}O_{2peak}$)). An alpha level $P<0.05$ was accepted to indicate statistical significance.

### 4.4 Results

Participant characteristics are displayed in Table 4.1.

Table 4.1 - Participants characteristics (n=17)

<table>
<thead>
<tr>
<th></th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>12.9 ± 0.5</td>
</tr>
<tr>
<td>Stature (m)</td>
<td>1.61 ± 0.07</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>52.1 ± 9.1</td>
</tr>
<tr>
<td>BMI (kg/m$^2$)</td>
<td>20.0 ± 2.9</td>
</tr>
<tr>
<td>Body Fat (%)</td>
<td>29.2 ± 7.3</td>
</tr>
<tr>
<td>Estimated maturity status from PHV (y)</td>
<td>1.02 ± 0.48</td>
</tr>
<tr>
<td>$\dot{V}O_{2peak}$ (mL.kg$^{-1}$.min$^{-1}$)</td>
<td>43.4 ± 5.9</td>
</tr>
<tr>
<td>Emotional eating (score between 1-3)</td>
<td>1.2 ± 0.3</td>
</tr>
<tr>
<td>External eating (score between 1-3)</td>
<td>1.5 ± 0.5</td>
</tr>
<tr>
<td>Restrained eating (score between 1-3)</td>
<td>1.9 ± 0.3</td>
</tr>
</tbody>
</table>

PHV = peak height velocity

#### 4.4.1 Energy intake

The *ad libitum* EI at the lunchtime meal was 2.92 ± 1.19 MJ for SED and 3.10 ± 1.20 MJ for EX, there were no significant differences for EI between the two conditions ($P>0.05$).
4.4.2 Energy expenditure

As expected the energy expended from 60 min of exercise (1.69 ± 0.28 MJ) was significantly higher (t = 6.86, P<0.001) following the EX condition compared to the SED condition (0.36 ± 0.09 MJ).

4.4.3 Water intake

Water intake was significantly higher (t = 6.86, P<0.001) in the EX condition (536 ± 178 mL) compared to the SED condition (251 ± 184 mL).

4.4.4 Appetite

Mean ratings of hunger are depicted in Figure 4.2, fullness in Figure 4.3 and prospective consumption in Figure 4.4. There was a significant difference between the four time points for ratings of hunger ($F_{(3,48)}$ 159.9, P<0.001), fullness ($F_{(3,48)}$ 120.1, P<0.001) and prospective consumption ($F_{(3,48)}$ 133.7, P<0.001). There were no significant differences between conditions for ratings of hunger ($F_{(1,16)}$ 1.15, P=0.30) fullness ($F_{(1,16)}$ 0.35, P=0.56) and prospective consumption ($F_{(1,16)}$ 0.03, P=0.86). Neither were there any significant differences for the interaction between condition*time for hunger ($F_{(3,48)}$ 1.615, P=0.20), fullness ($F_{(3,48)}$ 1.14, P=0.34) and prospective consumption ($F_{(3,48)}$ 2.65, P=0.06).
Figure 4.2 - Mean ± SD visual analogue scale (VAS) for subjective feelings of hunger (n = 17) in the sedentary (SED) and exercise (EX) conditions. Very hungry = 100.

Figure 4.3 - Mean ± SD visual analogue scale (VAS) for subjective feelings of fullness (n = 17) in the sedentary (SED) and exercise (EX) conditions. Very full = 100.
4.4.5 Percent energy compensation

Mean percent energy compensation was 17 ± 83 %, i.e. the girls compensated for 17 % of the energy cost of the exercise by increasing their EI in the EX condition when compared to the SED condition. Whilst the median of the groups was 18.1 % and the 25th and 75th percentiles were -48.4 % and 75. % respectively. However the range was -160 % to 166 %. Percent energy compensation for each participant is shown in Figure 4.5. There were no significant correlations (P>0.05) for percent energy compensation to any of the anthropometric measures (-0.42 < r > 0.36). Neither were there any significant correlations to any of the three eating behaviours (-0.04 < r > 0.33).
Figure 4.5 - Percent energy compensation for each participant (n = 17). 100 % would suggest that the energy intake had increased in the exercise condition when compared to the sedentary condition, to match the energy cost of the imposed exercise.

4.5 Discussion

The main aim from this study was to assess whether habitually active girls were able to alter their EI to compensate for an imposed bout of moderate intensity exercise and secondly whether there would be any acute changes in appetite. The adolescent girls were found, on average, to increase their intake following a bout of moderate intensity exercise compared to the sedentary condition, however this change was not significant. There were also no significant changes in appetite between conditions, indicating the exercise bout had no significant acute effects on appetite. Therefore the first hypothesis is rejected. The second hypothesis stated the EI increase following the EX condition would accurately match the EE of the exercise. As on average only 17 % of the energy expended from the exercise was compensated for by an increase in EI, the second hypothesis is also rejected.
4.5.1 Energy intake

The imposed bout of moderate intensity exercise failed to significantly alter acute EI when compared to a sedentary condition in habitually active girls. This is a similar finding to that of Bozinovski et al. (2009) who in a population group of 14 boys and 15 girls found no significant changes to EI following 45 min of walking exercise at the slightly higher intensity of VT compared to our study of 60 min walking at 80 % GET. However our findings are not comparable to that of Rumbold et al. (2011) who found netball trained girls would increase their intake compared to the sedentary condition following a 47 min netball exercise session. Although the population group of highly active girls are comparable to Rumbold and colleagues study (2011), the exercise intervention from the present study (walking exercise at 80 % GET for 60 min) was not comparable to Rumbold and colleagues (2011; 47 min of netball exercise). Similarly the follow up duration post exercise bout was also not comparable between the studies with the present study lasting less than 2 h post exercise and Rumbold and colleagues (2011) following up for a further 2 and a half days. Therefore, the findings from the current study present new data suggesting there are no changes to acute EI following a moderate intensity exercise bout in habitually active girls.

4.5.2 Energy compensation

As mentioned previously, the average compensation for the exercise bout was $17 \pm 83 \%$, suggesting that as a group, the exercise bout would induce a relative energy deficit, supporting the use of exercise to prevent weight gain. However, further investigations on the individual level (Figure 4.5) indicated that the range of compensation was from $-160 \%$, where intake was less in the EX condition therefore exacerbating the relative energy deficit up to $+166 \%$. 
thereby creating an acute positive energy balance. However, this suggestion is based on the assumption that the intake consumed from the SED condition was the quantity required to maintain energy balance. With such a large range for changes in EI post exercise, correlations between anthropometric and eating behaviour measures were investigated with the aim of finding an explanation as to why there was such a large variation between participants. The percent compensation was not significantly correlated to any of the measures taken within this investigation. This makes it challenging to draw any conclusions as to why there was such a large inter-individual response to changing EI following an imposed bout of moderate intensity exercise. Finding such a large variance between participants for changes in EI following a bout of exercise is not novel, as large standard deviations surrounding EI have previously been reported in the adult literature; see meta analysis by Schubert et al. (2013). The factors motivating this high variability between participants remain to be determined in both the adult and children’s literature and therefore an area recommended for future research. These findings highlight the importance of individual exercise prescription, as an imposed moderate intensity exercise bout can alter acute EI dramatically between individuals. Particularly as 4 of the 17 individuals increased their EI following the exercise above the energy deficit created by the exercise. Should these 4 girls perform moderate intensity exercise regularly, purely from an energy-balanced stance, they would gain weight over time should they continue to increase their EI above the energy deficit created by the exercise.

4.5.3 Energy expenditure

As expected the EX condition created an acute energy deficit by increasing the EE significantly (1.69 ± 0.28 MJ) when compared to the SED condition (0.36 ±
0.09 MJ). As the mean increase of EI in the EX condition compared to the sedentary condition was 0.18 ± 1.05 MJ, the imposed exercise bout would have created on average an acute energy deficit of approximately 1.5 MJ. This suggests that on average, moderate intensity walking exercise is a suitable intervention to create an energy deficit, should this be desired. However, considering the individual differences previously discussed based on percent compensation, averaging the impact moderate intensity exercise has on energy balance to a group of highly active adolescent females and making exercise prescription suggestions based on this, is not recommended.

4.5.4 Water intake

Similarly it was unsurprising that water intake was significantly higher in the EX condition (536 ± 178 mL) when compared to the SED condition (251 ± 184 mL). Although water intake was not a key variable within the present study, controlling water intake should be considered, as an increase in water prior to an eating occasion has been shown to reduce food intake (Flood, Roe, & Rolls, 2006; DellaValle, Roe, & Rolls, 2005). However, despite the increase in water intake following the EX condition, it appears EI was not reduced as it might have been based on the suggestions of Flood et al. (2006) or DellaValle et al. (2005) as overall EI was on average increased. It was therefore concluded that the increase in water intake following the EX condition was primarily based on the participants rehydrating themselves following the exercise condition and that this increase appeared to have no apparent impact on EI.

4.5.5 Appetite

The current paediatric literature reports equivocal findings for changes in appetite post exercise. Bellissimo et al. (2007), Tamam et al. (2012), Rumbold
et al. (2011) and Bozinovski et al. (2009) (long duration exercise) report an increase in appetite, whilst Bozinovski et al. (2009) (short duration exercise) and Moore et al. (2004) (high intensity exercise) report a decrease in appetite and Moore et al. (2004) (moderate intensity exercise) and Dodd et al. (2008) report no change to appetite. The present study indicated no significant differences between conditions for any of the appetite sensations measured. The primary suggestion as to why no changes in appetite were observed between conditions would be based on the exercise not being of a high enough intensity to suppress appetite. High intensity exercise is more likely to suppress appetite than moderate intensity exercise (Elder & Roberts, 2007). Secondly, changes in appetite might have occurred over time points not captured by the administration of the VAS. Infrequent administration of the VAS over the testing period is therefore a limitation to the present study. Finally, it could be hypothesised that any changes in appetite typically seen in non-habitually active individuals, may not be triggered following a bout of exercise in habitually active individuals, as they may be used to the feelings post exercise and do not associate them with a change in appetite.

4.5.6 Strengths and Limitations

Strengths of this study would be the robust within subjects’ design that limits the error variance associated with individual differences. The large participant number used, particularly in comparison to previous paediatric literature and over such a narrow age range. The use of a homogenised meal that prevented any changes in satiety should a mixed macronutrient composition meal had been used. Finally a strength to this study was the precise methods used to measure EI and EE, resulting in accurate measurements, a novel approach to be used in specifically active adolescent children.
In addition to the limitation already acknowledged surrounding the infrequent administration of the VAS. The limitation of conducting the study within the controlled environment of the research laboratory is also acknowledged. Whilst this allowed for robust and accurate measures of EI and EE, this environment was not habitual and did not allow for a free choice of food found within free-living conditions. Similarly, as sedentary behaviour was encouraged throughout both conditions when not exercising, any subconscious increases in sedentary behaviour following the exercise bout were not possible. This is of particular importance as the Earlybird study found children compensated for an imposed bout of exercise by increasing sedentary behaviour later that day (Frémeaux et al., 2011).

4.6 Conclusion

An imposed bout of moderate intensity exercise did not significantly alter EI or appetite in habitually active girls when compared to a sedentary condition. Habitually active girls were unable to accurately increase their EI to meet the increased EE following the exercise bout as on average only 17 % of the increased EE was compensated for. However, changes in EI following a bout of exercise are encouraged to be assessed on an individual basis, based on the observed wide variability for changes in EI (-160 – 166 % compensation) between participants. Further research is required to identify characteristics that may explain the large range between participants for their change in EI following exercise as those assessed within this study (anthropometric and eating behaviour measures) failed to elude an explanation.
5 The acute effects of maximal sprint interval exercise on energy intake and appetite in adolescents

5.1 Abstract

Acute effects of maximal sprint interval exercise (MSIE) on energy intake (EI) and ratings of subjective appetite (hunger, fullness and prospective consumption) were compared to a sedentary condition (SED) in thirteen boys and thirteen girls (12-13 y). Eating behaviours (emotional, restrained and external eating) were also investigated as potential attributors for the large variability commonly found for compensatory EI. MSIE comprised of fifteen 10 s maximal sprint cycling exercise each followed by 110 s of active recovery. A homogenised macronutrient composition lunch was offered ad libitum and weighed EI was recorded. Subjective appetite was rated throughout the test period. EI at the lunchtime meal was significantly greater following MSIE compared to SED (P<0.05) for the boys. There were no significant changes to EI between conditions for the girls. MSIE acutely reduced hunger and prospective consumption and acutely increased fullness in boys (P<0.05) but not girls (P>0.05), however by lunch (1 h post exercise) all appetite scores had recovered for the boys to match that of the SED condition. Measures of eating behaviour did not significantly correlate with EI in either condition. This is the first study to indicate acute changes to EI and appetite following MSIE in boys, but not girls in a controlled laboratory environment. These findings may suggest the utilisation of sex specific exercise modality prescriptions as a method of appetite and EI control for this age group.
5.2 Introduction

The effect of exercise-induced increased EE on subsequent EI and subjective ratings of appetite has been investigated and reviewed in adults (Blundell et al., 2003; Elder & Roberts, 2007; Martins et al., 2008; Bilski et al., 2009), with limited research conducted within the lean paediatric population (Moore et al., 2004; Bellissimo et al., 2007; Dodd et al., 2008; Bozinovski et al., 2009; Nemet et al., 2010). Changes to EI and/or appetite following exercise have most often been attributed to the type of exercise intervention implemented or to sex differences. Another variable suggested to affect EI has been eating behaviours, however this area has received a limited focus to date (Lluch et al., 2000).

5.2.1 Exercise intervention

Typical exercise interventions utilised within the lean paediatric population when assessing the effects of exercise on EI and/or appetite have been either continuous moderate intensity (Bellissimo et al., 2007; Bozinovski et al., 2009; Moore et al., 2004; Tamam et al., 2012) or continuous high intensity exercise (Dodd et al., 2008; Moore et al., 2004; Tamam et al., 2012). Two studies have investigated typical sporting activities: Netball (Rumbold et al., 2011) and Swimming/Resistance exercise (Nemet et al., 2010). However, both Rumbold et al. (2011) and Nemet et al. (2010) performed their investigations out of the laboratory and so measurements of EE and for Rumbold et al. (2012) also measures of EI, were compromised on accuracy. To date maximal sprint interval exercise (MSIE) has not been investigated in lean children within the controlled laboratory setting.
Sprint intensity exercise interspersed with periods of low- to moderate-intensity exercise has been suggested to be more representational of children’s activity patterns under natural conditions (Bailey et al., 1995). A bout of high intensity interval exercise (HIIE) was rated equally enjoyable to a bout of moderate intensity exercise in a group of 14 y boys, (Cockcroft et al., 2014). Acute changes to EI and appetite to date have only been investigated once within an obese adult male population (Sim, Wallman, Fairchild, & Guelfi, 2014) and once with an obese paediatric male population (8-12 y; Crisp, Fournier, Licari, Braham, & Guelfi, 2012). Sim and colleagues (2014) reported a reduction in EI following both HIIE (60 s at 100 % \( \dot{V}O_{2peak} \) and 240 s at 50 % \( \dot{V}O_{2peak} \)) and very high intensity intermittent exercise (VHIIE; 15 s at 170 % \( \dot{V}O_{2peak} \) and 60 s at 32 % \( \dot{V}O_{2peak} \)) when compared to a rest condition. Similarly Crisp and colleagues (2012) observed a reduction in EI following exercise at Fat\(_{max}\) with a 4 s interspersed maximal sprint every 60 s for 30 min compared to 30 min of exercise at Fat\(_{max}\) alone (no sprints). There were no significant differences between conditions for ratings of appetite for either Sim et al. (2014) or Crisp et al. (2012) investigations. Whether lean girls as well as boys also reduce their EI following a bout of MSIE compared to a control condition remains to be investigated.

### 5.2.2 Sex differences

Primarily within the paediatric literature when investigating acute changes for EI and/or appetite following a bout of exercise, either boys or girls are recruited (Moore et al., 2004; Bellissimo et al., 2007; Dodd et al., 2008; Rumbold et al., 2011 and Tamam et al., 2012). To date there are two published studies one in lean 9-14 y children (Bozinovski et al., 2009) and one in obese 14.1 ± 1.8 y children (Thivel et al., 2011) that recruited and compared participants from both
sexes. Neither paper reported any sex specific differences between conditions for EI or appetite. Although Bozinovski et al. (2009) did report the boys ate significantly more than the girls for each condition investigated. This is in contrast to the adult literature where appetite, EI and appetite stimulating hormones differences have been observed between males and females following exercise interventions (Hagobian et al., 2009; Stubbs et al., 2002a, 2002b; Ebrahimi et al., 2013). Recruiting children over an age range of key maturational differences was deemed most appropriate for this investigation.

5.2.3 Eating behaviour

Eating behaviour, particularly restrained eating, has been suggested as a variable that could potentially influence EI following exercise (Lluch et al., 2000). Lluch and colleagues (2000) found a positive correlation between dietary restraint in females and EI following a period of rest, but not after a bout of exercise. Large individual variability to changes in EI following exercise have previously been reported in the adult literature (Finlayson, Bryant, Blundell, & King 2009; Finlayson et al., 2011; Unick et al., 2010). If correlations between eating behaviours (emotional, restrained and external eating) and the variability in EI following EE exist, this may go some way towards explaining the individual differences previously found (chapter 4). Eating behaviours have not yet been correlated to changes in EI following EE in children.

The aims of the present study were twofold, firstly, to examine the acute effects of MSIE on EI and appetite in both boys and girls. Secondly, to understand how eating behaviour might impact EI responses following exercise. Therefore based on the findings from the current literature in adults, the hypotheses are (1) EI will reduce acutely following a bout of MSIE, (2) MSIE will not alter
appetite, (3) restrained eating behaviour will negatively correlate to increases in EI following exercise.

5.3 Method

5.3.1 Participants

Thirteen healthy boys aged 12.8 (mean ± 0.3) y and 13 healthy girls 13.1 (± 0.3) y from a school in the South West of England volunteered to participate in this study. The Institutional Ethics Committee approved the study and once fully informed of all procedures, written informed consent was obtained from the parents or guardians and informed assent from adolescents. A brief medical history and food intolerance questionnaire was used to exclude adolescents with a history of diabetes or other metabolic disorders known to affect intermediary metabolism.

5.3.2 Design

The study compared EI and appetite responses from a lunchtime meal in adolescent boys and girls following a period of being sedentary (SED) or after completing a MSIE session. A within-subjects design was utilised and the participants were randomly assigned to either the SED or MSIE condition in a counterbalanced order. Participants attended the Research Centre in pairs on three occasions separated by a minimum of 7 d but no longer than 21 d. Where possible, testing occurred on the same day of the week. The three visits consisted of an initial visit for familiarisation and preliminary measurements followed by the SED or MSIE conditions where one participant completed the MSIE condition and the
other SED to allow independent data collection and avoid peer influence (Figure 5.1).

<table>
<thead>
<tr>
<th>Time</th>
<th>0830</th>
<th>0900</th>
<th>0930</th>
<th>1000</th>
<th>1030</th>
<th>1100</th>
<th>1130</th>
<th>1200</th>
<th>1230</th>
<th>1300</th>
</tr>
</thead>
<tbody>
<tr>
<td>VAS</td>
<td>*</td>
<td></td>
<td></td>
<td>*</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Figure 5.1 - Experimental design: Participants undertook 2 conditions; maximal sprint intensity exercise (MSIE) and a sedentary condition (SED). VAS * indicates the time points where the appetite Visual Analogue Scales were recorded.

5.3.3 Body composition

Stature and sitting stature were measured to the nearest 0.01 m (Seca stadiometer, SEC-225, Seca, Hamburg, Germany). Body weight was measured to the nearest 0.1 kg (Hampel digital scales sensitive to 100 g, Hampel XWM-150K, Hampel Electronics Co. Taiwan) in light sports clothing and no shoes. Body density was measured by air displacement plethysmography, (Life measurement instruments, Concord, CA, USA) in accordance with the methodology of Dempster and Aitkins (1995). An estimation of maturity status was also calculated (Mirwald et al., 2002). Table 5.1 represents the anthropometric characteristics of the participants.

5.3.4 Preliminary visit

Heart rate (HR) monitors were fitted to adolescents before commencement of exercise. Participants completed an incremental ramp test to volitional exhaustion for determination of $\dot{V}O_2$peak on a cycle ergometer (Lode Excalibur Sport V2, Lode BV, Groningen, The Netherlands). Participants initially peddled at $75 \pm 5$ rpm for a 3 min warm-up at 25 W. Following the warm-up this cadence
was maintained whilst resistance increased continuously by 25 W min\(^{-1}\) to attain a test approximately 8-10 min in duration. HR was continually monitored and manually recorded during the last 10 s of each minute of exercise together with a rating of perceived exertion (RPE) using the 1-10 Pictorial Children’s Effort Rating Table scale (Yelling et al., 2002). Participants were actively encouraged to continue until volitional exhaustion. Maximal effort was considered to be attained if, in addition to subjective indication of intense efforts (e.g. unable to maintain the cadence, RPE > 9, facial flushing, sweating, discomfort), RER reached a value > 1.1 and maximal HR was ≥ 95 % of age-predicted maximum (220 – chronological age). All participants satisfied these criteria. For each participant, oxygen consumption (\(\dot{V}O_2\)), expired carbon dioxide (\(\dot{V}CO_2\)), minute ventilation (\(\dot{V}E\)), and respiratory exchange ratio (RER) were calculated from the expired air samples using a respiratory gas analyser (Cortex Metalyzer 3B, Germany and Metasoft v2.1 software). The respiratory gas analyser was calibrated to manufacture guidelines for each participant and expired air was collected and recorded breath by breath throughout the exercise test. \(\dot{V}O_2\)\(_{\text{peak}}\) was taken as the absolute highest value before cessation of the exercise test.

Before leaving the research centre the adolescents were asked to select their preferences for breakfast (choice of cereal or toast) and lunch (choice of sandwich fillings) so that acceptable meals could be provided to them on both subsequent experimental days. To ascertain measures of eating behaviour, the adolescents were also asked to complete the DEBQ-C (van Strien & Oosterveld, 2008).

5.3.5 Testing days

Participants arrived at the laboratory at 0830 h following a 12 h overnight fast. Between 0840 h and 0900 h participants consumed an *ad libitum* breakfast.
Intake weight was recorded to standardise breakfast for the subsequent testing day. Breakfast intake was not included in any of the EI calculations for two reasons. Firstly, breakfast remained a constant for each child between conditions and secondly, the study was designed to investigate any acute compensation effects from morning exercise on lunch EI only. Additional standardisation included participants’ recall of the dinner meal from the previous night that was recorded and requested to be repeated before the next test visit. This was verbally verified on the subsequent visit.

Participants remained sedentary in the laboratory before and following the exercise or sedentary condition protocol by reading, completing homework, watching DVDs or playing computer games.

### 5.3.5.1 Exercise day

The exercise started 2 h after breakfast (1050 h) for all participants. The protocol commenced with a 5 min warm up, pedalling at 25 W at a self-determined cadence, but actively encouraged to be below 50 rpm, after which the MSIE bout began. The work rate resistance was applied, calculated from 70 g kg body weight (BW)^{-1} for boys and 67 g kg BW^{-1} for girls for 10 s (Bar-Or, 1987). Different work rates were selected for each sex, as previous literature has indicated that the force needed to yield the highest mean power differs between the sexes (Bar-Or, 1987) and when the resistance is the same, girls end up working on average 19 % harder than boys (Welsman et al., 1997). However, as the work rates were ultimately different between the sexes, sex comparison analysis was not appropriate. Settings on the electronically braked cycle ergometer allowed the work rate to be added at a rate of 1000 W per second ensuring a negligible delay in achieving the desired work rate. In the lead up to the sprint, the participants were given a 5 s count down to gradually
increase the pedal cadence before the load was added. The adolescents were asked to sprint for the duration of the 10 s and were given verbal encouragement to ensure completion of each sprint. After each sprint the adolescents were asked to reduce their pedal cadence (between 30-40 rpm), whilst the power output was reduced to 25 W for 110 s of active recovery. In total the exercise lasted 40 min and incorporated 15 sprints and a 5 min warm up and cool down period. Between 3 and 5 of these sprints were practiced on the preliminary day so the adolescents understood the procedures of the test exercise.

EE was calculated (Weir, 1949) using the expiration data collected from the respiratory gas system (oxygen consumption (\(\bar{V}O_2\)) and expired carbon dioxide (\(\bar{V}CO_2\))).

Following the exercise bout the participants were offered 250 mL of water to rehydrate. Any water remaining was measured and recorded, aiming to control any EI or appetite altering effects from water consumption. Consumption of fluids, both energy and non-energy containing, has previously been found to alter appetite and EI (Flood et al., 2006; DellaValle et al., 2005). The participants were then asked to resume their chosen sedentary activity.

5.3.5.2 Sedentary day

As with the exercise day, the participants performed sedentary activities following breakfast. To mimic water provisions offered on the exercising day, all participants were offered a 250 mL cup of water at 1130 h, any water remaining was weighed and recorded. At 1140 h, resting expired air samples were collected through the respiratory gas system for 15 min in a seated position. As with exercise EE, the sample was analysed for oxygen consumption (\(\bar{V}O_2\)), expired carbon dioxide (\(\bar{V}CO_2\)) and used to calculate EE at rest (Weir 1949).
5.3.5.3 Lunch provisions

The lunchtime meal was offered *ad libitum*, to all participants at 1230 h, (1 h after exercise had concluded). All test meals were prepared by one researcher and designed to mimic the participants’ usual intake on a normal school day. Lunch consisted of sandwiches (a choice from: cheese and margarine; sausage, margarine and ketchup; chocolate spread; jam and margarine, or peanut butter and margarine) and a plain sponge cake with vanilla frosting. The same selected choice of sandwich was provided for each test visit. Each food item had a homogenised macronutrient composition of 53 % energy from carbohydrate, 35 % from fat and 12 % from protein to prevent any effects of macronutrient satiety hierarchy (Department of Health, 1991) or changes in macronutrient preferences following exercise (Nemet *et al.*, 2010). The macronutrient composition is similar to the average macronutrient requirement for adolescents of this age group (Department of Health, 1991). As the meals were offered *ad libitum*, volumes of food placed on the plate were offered in excess of requirement and were similar to the daily estimated average requirements of energy for adolescents of this age (10 MJ for boys and 8 MJ for girls) (Department of Health, 1991). This was split into 6 MJ of sandwiches and 4 MJ of cake for the boys and 4 MJ of sandwiches and 4 MJ of cake for the girls. Each food item was cut into bite-sized pieces to disguise the quantity being offered. Such large amounts of food were offered to encourage the adolescents to eat until they felt comfortably full and not when the plate was empty. The adolescents were informed that they were not expected to finish the plates of food however; more could be provided if requested. A 250 mL glass of water was offered with the lunch meal. Food and water intakes were calculated from subtracting the final plate/glass weight from the initial
plate/glass weight to the nearest 1 g (Air Super Slim Kitchen Scales, Salter, UK). Adolescents were separated from one another for the lunch meal and constantly observed by the researcher who sat between the two rooms; interactions with the researcher were kept to a minimum. Participants had until 1300 h to finish their meal (30 min).

5.3.5.4 Appetite ratings

At set times throughout the SED and MSIE conditions (0930 h, 1045 h, 1130 h, 1200 h, 1230 h and 1300 h) adolescents were asked to rate their hunger, fullness and prospective consumption (desire to eat) on a Visual Analogue Scale (VAS) 100 mm line (Moore et al., 2004; Dodd et al., 2008). 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. VAS were chosen to measure appetite as they are the most commonly used tool available for use with children (Bellissimo et al. 2007; Bozinovski et al. 2009; Dodd et al., 2008; Moore et al., 2004; Rumbold et al., 2011 and Tamam et al. 2012). VAS have also been validated as a reliable and reproducible tool for measuring pain in children (Shields et al., 2003; McGrath et al., 1996).

5.3.6 Calculation of energy expenditure

EE for the SED and MSIE conditions was calculated using the $\dot{V}O_2$ and $\dot{V}CO_2$ output from the respiratory gas system expressed as 1 s readings. EE per 1 s was calculated using the respiratory quotient equations by Weir (1949) and
totalled to give exercising EE from the 40 min bout and resting EE for a 40 min period.

5.3.7 Statistical analysis

Descriptive statistics of mean and standard deviation of the data are presented unless otherwise stated. EI, EE and water consumption were investigated separately for boys and girls using Students paired t-test.

Markers of appetite from the VAS: hunger, fullness and prospective consumption were investigated using mixed model ANOVA (2x6) for condition and time and any interactions for condition*time. Any significant findings were further investigated with Bonferroni corrected post hoc tests.

Pearson’s product moment correlations were performed between the 3 behavioural eating responses calculated from the DEBQ-C and EI for both conditions. The data were analysed using SPSS (version 20 for Mac, SPSS Inc., Chicago, US). Statistical significance was accepted at P<0.05, except for the results from Students paired t-tests where the alpha level was adjusted with a Bonferroni correction to P<0.025.
5.4 Results

Participant characteristics are displayed in Table 5.1.

Table 5.1 - Participant physical and physiological characteristics

<table>
<thead>
<tr>
<th></th>
<th>Boys (n=13)</th>
<th>Girls (n=13)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stature (m)</td>
<td>1.57 ± 0.07</td>
<td>1.63 ± 0.05</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>47.2 ± 8.2</td>
<td>50.1 ± 5.7</td>
</tr>
<tr>
<td>BMI (kg/m^2)</td>
<td>18.9 ± 2.1</td>
<td>18.9 ± 2.1</td>
</tr>
<tr>
<td>Body Fat (%)</td>
<td>26.7 ± 7.8</td>
<td>25.2 ± 7.3</td>
</tr>
<tr>
<td>Estimated maturity status from PHV (y)</td>
<td>2.3 ± 0.8</td>
<td>1.2 ± 0.2</td>
</tr>
<tr>
<td>(\dot{V}O_{2\text{peak}}) (mL·kg(^{-1})·min(^{-1}))</td>
<td>50.5 ± 4.6</td>
<td>44.1 ± 9.2</td>
</tr>
<tr>
<td>Emotional eating</td>
<td>1.25 ± 0.25</td>
<td>1.22 ± 0.26</td>
</tr>
<tr>
<td>Restrained eating</td>
<td>1.89 ± 0.48</td>
<td>1.73 ± 0.65</td>
</tr>
<tr>
<td>External eating</td>
<td>2.12 ± 0.41</td>
<td>1.64 ± 0.44</td>
</tr>
</tbody>
</table>

All values are mean and standard deviation (SD); Peak Height Velocity (PHV)

5.4.1 Energy intake

Boys: EI was significantly higher (P=0.011) following MSIE (4.14 ± 1.04 MJ) compared to the SED condition (3.58 ± 0.87 MJ).

Girls: There were no significant differences for EI (P=0.748) between MSIE (3.30 ± 0.92 MJ) and the SED condition (3.37 ± 0.88 MJ).

5.4.2 Energy expenditure

Boys: EE was significantly higher (P<0.001) following MSIE (0.83 ± 0.06 MJ) compared to the SED condition (0.23 ± 0.03 MJ).

Girls: EE was significantly higher (P<0.001) following MSIE (0.69 ± 0.10 MJ) compared to the SED condition (0.21 ± 0.03 MJ).
5.4.3 Water intake

Boys: Water intake was significantly higher (P=0.004) following MSIE (339 ± 122 mL) compared to the SED condition (221 ± 182 mL).

Girls: There were no significant differences for water intake (P=0.307) between MSIE (260 ± 163 mL) and the SED condition (215 ± 142 mL).

5.4.4 Appetite – hunger

Mean ratings of hunger are depicted in Figure 5.2 for both boys and girls.

Boys: A significant effect of time (F (2.664,31.967) = 56.933, P<0.001) and time*condition (F (5,60) = 3.069, P=0.016) were found. There was not a significant effect for condition (P>0.05). Post hoc pairwise comparisons indicated the boys’ felt significantly less hungry on the MSIE condition at time point 1130 h when compared to the SED condition (P=0.037, mean change 23 mm).

Girls: A significant effect of time was found (F (2.070,24.841) = 32.186, P<0.001). There were no significant effects between condition (P>0.05) nor an interaction effect of time*condition (P>0.05).
Figure 5.2 - Mean (±SE) visual analogue scales (VAS) for subjective feelings of hunger in boys (n=13) and girls (n=13) on sedentary (SED) and maximal sprint interval exercise (MSIE) conditions. Very hungry = 100. Intervention (i.e. 40 min of exercise or rest); lunch meal. * Indicates a significant difference at the time point (P>0.05) between conditions.

5.4.5 Appetite – fullness

Mean ratings of fullness are depicted in Figure 5.3 for both boys and girls.

Boys: A significant effect of time ($F_{(2.485,29.784)} = 56.747$, $P<0.001$) and time*condition ($F_{(5,60)} = 3.447$, $P=0.008$) were found. There was not a significant effect for condition ($P>0.05$). Post hoc pairwise comparisons indicated the boys’ felt significantly more full on the MSIE condition at time point 1130 h when compared to the SED condition ($P=0.049$, mean change 23 mm).

Girls: A significant effect of time was found ($F_{(1.880,22.564)} = 40.524$, $P<0.001$). There were no significant effects between condition ($P>0.05$) nor time*condition ($P>0.05$).
5.4.6 Appetite – prospective consumption

Mean ratings of prospective consumption are depicted in Figure 5.4 for both boys and girls.

Boys: A significant effect of time ($F_{(3.185,38.219)} = 50.130, P<0.001$) and time*condition ($F_{(5,60)} = 3.299, P=0.011$) were found. There was not a significant effect for condition ($P>0.05$). Post hoc pairwise comparisons did not reveal any statistically significant differences for any of the individual time points between conditions.

Girls: A significant effect of time was found ($F_{(1.735,20.824)} = 48.808, P<0.001$). There were no significant effects between condition ($P>0.05$) nor time*condition ($P>0.05$).
5.4.7 Eating behaviour

There were no significant correlations for the three eating behaviours (emotional, restrained and external) and EI following either the SED or MSIE conditions for the boys. Emotional eating was significantly correlated to EI on the SED but not MSIE condition for the girls. All other eating behaviours were not significantly correlated to either condition for the girls. Results are shown in Table 5.2.

Table 5.2 - Pearson’s correlation coefficients for eating behaviours against energy intake for the maximal sprint interval exercise (MSIE) and sedentary (SED) conditions.

<table>
<thead>
<tr>
<th></th>
<th>MSIE</th>
<th>SED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Boys (n=13)</td>
<td>Girls (n=13)</td>
</tr>
<tr>
<td>Emotional</td>
<td>r = 0.14</td>
<td>r = -0.27</td>
</tr>
<tr>
<td></td>
<td>P = 0.66</td>
<td>P = 0.37</td>
</tr>
<tr>
<td>Restrained</td>
<td>r = 0.17</td>
<td>r = 0.09</td>
</tr>
<tr>
<td></td>
<td>P = 0.58</td>
<td>P = 0.77</td>
</tr>
<tr>
<td>External</td>
<td>r = 0.05</td>
<td>r = -0.15</td>
</tr>
<tr>
<td></td>
<td>P = 0.87</td>
<td>P = 0.62</td>
</tr>
</tbody>
</table>
5.5 Discussion

The first aim of this study was to examine the acute effects of a bout of MSIE on EI and ratings of appetite in adolescent boys and girls. Following MSIE when compared to the SED condition, EI was significantly increased in the boys. The girls did not significantly alter their EI between conditions. Therefore, rejecting our first hypothesis for both the boys and the girls that EI will reduce acutely follow MSIE. There were no significant differences for appetite between conditions for either boys or girls. However, a significant effect of time was found for both boys and girls and a significant interaction effect for condition and time was found for the boys. Therefore, the second hypothesis (that there will be no significant changes to appetite between conditions) is accepted for the girls but rejected for the boys. Our second aim and third hypothesis was to test whether eating behaviours impacts EI following exercise. Emotional eating was found to significantly correlate to EI on the SED condition but not for the MSIE, with the girls only. Therefore, the third hypothesis is rejected for the boys for all three eating behaviours and accepted for the girls in terms of emotional eating behaviours but rejected for restrained and external eating behaviours.

5.5.1 Energy intake

The observed significant increase in EI following MSIE for the boys and no significant change for the girls is in comparison to the findings by Sim et al. (2014) in adults and Crisp et al. (2012) in obese children, where both studies indicated a reduction in EI following MSIE. Differences in methodologies may explain the variance between the results. Firstly, Sim et al. (2014) and Crisp et al. (2012) recruited obese participants, whilst the adolescents recruited to the present study were lean. Unlike the present study where there was a 60 min
time delay between the cessation of the exercise test and provision of the test meal, Crisp et al. (2012) initiated their test meal 5-10 min after the cessation of the exercise. Although Sim et al. (2014) provided their test meal 70 mins post exercise, they had already instructed their participants to consume 1.1 MJ of a liquid meal within 5 mins of the cessation of exercise test to enable postprandial responses of appetite-related blood variables to be measured. The test meal was offered with a time delay in the present study, as it was deemed more indicative of habitual activity, both in school (where lessons occur following bouts of activity performed during break times) and outside of the school environment (where travel time often occurs between the location of the physical activity and the meal location).

Another potential explanation for the adolescent boys significantly increasing their EI following MSIE could be based on an exercise-induced increase in hedonic reward following the heavy exertion of performing maximal sprint exercise. The construct of hedonic reward has been reviewed by Elder and Roberts (2007) and theorised as an, ‘increase in intermittent hunger associated with exercise would result in greater hedonic rewards for eating (i.e. greater enjoyment of foods), whilst at the same time overall levels of hunger would be decreased’ (pp 11). Applying this theory to our results suggests that the hedonic reward maybe higher in boys based on their significant increase in EI following exercise, compared to the girls who were working at a slightly lower intensity and may therefore have not experienced the same hedonic reward following the exercise. This theory needs further explorative testing, particularly within the paediatric population.
5.5.2 Appetite

Finding a significant acute reduction in hunger and prospective consumption but and increase in fullness immediately following the MSIE compared to the SED condition in the boys was not comparable to the findings by Sim et al. (2014) or Crisp et al. (2012). HIE as opposed to MSIE has been shown to suppress hunger in lean males in both the adult literature (Thompson et al., 1988; Pomerleau et al., 2004; King & Blundell, 1995; King et al., 1996) and paediatric literature (Bozinovski et al., 2009). This may suggest perhaps, the differences observed between the present study and that of Sim et al. (2014) and Crisp et al. (2012) who recruited only obese participants could be attributed to body size differences.

The mechanism behind the suppression in hunger and prospective consumption but increase in fullness following exercise was theorised by Blundell et al. (2003) as a redirection of blood flow, towards the muscles, away from splanchnic circulation following high intensity exercise. With only the boys displaying a change in appetite and their slightly higher exercise work rate, when compared to the girls, may explain why only the boys expressed an acute change in appetite and the girls did not.

Appetite scores for the boys returned to match those of the control condition 1 h post exercise (when the meal was administered), suggesting the time delay between completion of the exercise and provision of the test meal allowed the blood flow to return towards the splanchnic circulation, thus in turn losing the anorexic effect on appetite. As mentioned previously, the time delay between cessation of the exercise bout and provision of the test meal was chosen to increase the external validity of the findings. Comprehensive investigations altering the time between completion of exercise and provisions of the test meal
have yet to be explored within the paediatric population. Suggested future work would also include examining any specific sex changes following work matched exercise at different intensities also within the paediatric population.

5.5.3 Water intake

Although water intake was not a key variable within this study, it was important to monitor and control the intake between conditions as fluid consumption impacts EI and appetite (Flood et al., 2006; DellaValle et al., 2005). The adolescents were offered 250 mL at two time points for both conditions, 1130 h immediately post exercise (if on the MSIE condition) or after a period of rest if on the SED condition and also at 1230 h with their lunch meal. There were no significant differences between conditions for the girls, however the boys consumed significantly more water on the MSIE condition (mean increase of 118 mL) compared to the SED. There is currently insufficient evidence to clarify the role water has on appetite and EI, within the paediatric literature, however there are some implications within the adult literature that consumption of water would increase energy consumption (Negoianu & Goldfarb, 2008), a theory that is comparable to our findings.

5.5.4 Eating behaviour

Observations of changes in EI from previous work, both published (Moore et al., 2004) and unpublished, within our laboratory has indicated standard deviations that are over 25 % of the mean value for post exercise energy compensation. Similarly, the present study also reported standard deviations of 25 % of the mean value for EI. This implies that changes in EI in response to imposed
exercise results in a large variable response between participants. Large variability for EI responses has also been reported in the adult literature in both lean (Finlayson et al., 2009) and obese females (Finlayson et al., 2011; Unick et al., 2010). For this reason, eating behaviours were examined as to whether they could potentially be a determining factor for such large inter-subject variability. Our findings indicated there were no significant correlations between eating behaviours (emotional, restrained and external) for EI for either condition with the boys. However, emotional eating was significantly negatively correlated to EI from the SED condition in the girls. This suggests that the more controlled eating behaviour is by emotion, the lower the total EI in a sedentary condition is likely to be. However, this is likely to be a chance finding as no significant correlations were found for emotional eating behaviours and EI following the MSIE condition which would be expected, as there were no significant differences for EI between conditions for the girls.

Investigations as to why there are such large inter-person differences between conditions for EI needs further exploration in both the adult and paediatric population as eating behaviour appears not to be an indicator.

5.5.5 Implications

The findings from the present study extend the current literature indicating significant changes for both EI and appetite in lean male adolescents following MSIE whereas MSIE has no significant effect on either EI or appetite for lean female adolescents. Future work should investigate how these paediatric findings could underpin sex specific exercise recommendations as a method of EI and appetite control within the lean adolescent population. Reporting similar exercise interventions for both sexes are sparsely investigated for this area.
within the paediatric population. Therefore these findings are novel to the area and to the current literature.

5.5.6 Strengths and Limitations

Similar to the study reported in chapter 4, this studies strengths were also its’ robust within subjects’ design, the large participant number used, the use of a homogenised meal and the precise methods used to measure EI and EE. In addition, this study also recruited both boys and girls, adding to the literature surrounding sex comparisons in children, as to date only 1 normal weight study had done so. This study also developed a sustainable maximal sprint intensity exercise protocol that was suitable for children of this age group.

There are also a few limitations to be acknowledged. Although precise methods were used to measure EI and EE, this scenario is not indicative of free living. The present study only measured acute changes in EI in the subsequent meal, therefore any changes in eating or physical activity behaviours following the lunch meal were not monitored.

The exercise performed was highly controlled and therefore lacked ecological validity, but as studies with paediatric populations are sparse, the aim was to ensure the validity of the measurements, therefore restricting the feasibility of longer follow up periods, before conducting this type of investigation into a free living situation. Also, the exercise performed was not work matched for both the boys and the girls, which limited any conclusive sex comparison. However, ultimately a bout of MSIE was performed by both the boys and the girls, allowing some comparisons between the sexes.

Circulating hormones may influence appetite and eating behaviour (Davidsen, Vistisen, & Astrup, 2007). Therefore, a further limitation to this study was the
lack of control for whether the girls were menstruating, and if so what phase of the menstrual cycle they were in. Measuring whether the girls had begun menstruation and if so what phase of the cycle they were in should be controlled for in future research.

5.6 Conclusion

MSIE acutely suppressed hunger and prospective consumption whilst increase acutely fullness in boys but not girls, however by the time the lunch meal was administered, (1 h post exercise) appetite had recovered in the boys to match the SED condition. EI in the lunch time meal was significantly greater following MSIE compared to SED in the boys but not girls. Measures of eating behaviour (emotional, external and restrained eating) had no significant impact on EI for either sex. This is the first study to indicate significant sex differences for both EI and appetite in normal weight adolescents following MSIE.
6 The effects of a preload snack and moderate intensity exercise on acute appetite and energy intake in 12-14 y old adolescents

6.1 Abstract

Energy intake (EI) and energy expenditure (EE) should not be considered independent entities, more an inter-connected system. With increased physical activity and reduced snacking initiatives prevalent Public Health measures, any changes to subsequent EI should be monitored. The aim of this study was to investigate changes in acute EI and appetite over four conditions. 1) A control condition no snack or exercise (CON); 2) a snack condition (+1 MJ; SK); 3) a moderate intensity cycling exercise condition (-1 MJ; EX); and finally 4) both a snack and exercise (+1 MJ, -1 MJ; EXSK).

Acute changes in appetite (VAS; hunger, fullness and prospective consumption) and lunchtime EI (ad libitum pizza meal) were recorded in 20 boys and 18 girls (12-13 y).

Lunch EI was not significantly different between conditions or sexes (P>0.05). Relative EI indicated no significant differences between the sexes (P>0.05), however in the EX condition, relative EI was significantly lower (P<0.001) compared to all other conditions. Hunger and prospective consumption increased significantly over time (P<0.001) and was significantly higher in the CON and EX condition compared to the SK and EXSK. Whilst fullness significantly decreased over time (P<0.001) and was significantly lower in the CON and EX condition compared to the SK and EXSK. Again 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.

**6.2 Introduction**

The Health Survey for England (2012) indicated that the prevalence of overweight and obesity in children aged 11-15 y was 32.5 %, whilst 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 ‘knock-on’ changes to eating behaviours, which may impact upon energy balance, are considered.

There are two components that make up energy balance; EI and EE, which should not be considered as independent entities. Physical activity in the form of structured exercise directly effects energy balance through increasing EE and potentially creating an energy deficit. Conversely snacking of energy dense foods, something common in adolescents (Savige, MacFarlane, Ball, Worsley, & Crawford, 2007), impacts energy balance by increasing EI and potentially creating an energy surplus. Both the intake and the expenditure of energy are now more commonly considered as an inter-connected system (Thivel & Chaput, 2014).

Evidence surrounding whether increasing EE through imposed acute bouts of exercise will change subsequent EI in lean children and adolescents is still
inconclusive (Thivel et al., 2012). However, it has been proposed that acute and chronic increases in physical activity are more likely to impact energy balance through an indirect change in appetite and food intake, as opposed to an increased EE (Thivel et al., 2012). Similarly, servings per day of snack foods are not necessarily an independent determinant of weight gain in children and adolescents (Field et al., 2004). Therefore, elucidating the understanding of whether EI alters acutely in response to an increase in EE (moderate intensity exercise) or an increase in EI (mid-morning snack), or the combination of both, is a novel area of interest.

Previous research into the acute effects of exercise on EI and subjective appetite feelings in paediatrics, have predominantly been performed in the controlled environment of a laboratory (Moore et al., 2004; Dodd et al., 2008; Belissimo et al., 2007; Bozinovski et al., 2009). Consequently, the findings of these studies are limited by their generalisability. Therefore, increasing the external and ecological validity for the findings from future studies has been suggested by conducting the research in more habitual environments for children and adolescents, such as within the school.

The aim of the present study therefore, was to investigate whether an energy controlled mid-morning snack (~1 MJ), an EE (~1 MJ) from a controlled moderate intensity exercise session or both combined alter acute lunchtime intake. The second aim from the study was to determine whether subjective feelings of appetite were altered between conditions. The hypotheses are as follows:
1. Following a bout of moderate intensity exercise lunchtime EI and subjective feelings of hunger and prospective consumption would increase whilst fullness would decrease to compensate for the increase in EE. Based on the hypothesised increase in EI, relative EI would not be significantly different to the control condition.

2. Lunchtime EI would reduce and feelings of hunger and prospective consumption would decrease whilst fullness would increase for the snack condition compared to the control condition as the children compensate for their earlier EI from the snack. Based on the hypothesised decrease in EI, relative EI would not be significantly different to the control condition.

3. There would be no significant difference in lunchtime EI or feelings of appetite between the control condition and the exercise and snack condition as both conditions are energy matched. Relative EI would therefore not be significantly different to the control condition.

### 6.3 Methods

#### 6.3.1 Participants

Twenty boys aged 12.9 (± 0.3) y and 18 girls 13.1 (± 0.2) y, following an invitational meeting at their school in the South West of England, volunteered to participate in the study. 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 that had a history of diabetes or other metabolic disorders known to affect intermediary metabolism.

6.3.2 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. Participants were randomly assigned in a counterbalanced order to the four conditions. The four conditions were: 1) a control condition of no snack and no exercise (CON); 2) a snack condition where a mid-morning snack was consumed (totalling an EI of 1 MJ; SK) 3) an exercise condition where moderate intensity exercise was performed (totalling an EE of 1 MJ; EX) and finally 4) a condition where both a snack was consumed and moderate intensity exercise was performed (totalling EI of 1 MJ and EE of 1 MJ; EXSK).

Participants attended the research centre on one occasion in groups of four for preliminary measurements, followed by four visits to a temporary laboratory set up within the school to complete the remaining 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 portrayed in Figure 6.1.
Table 6.1 - Schematic of the protocol for each condition CON = control, EX = exercise, SK = snack, EXSK = exercise and snack

<table>
<thead>
<tr>
<th>Time</th>
<th>0800h</th>
<th>0855h</th>
<th>0955h</th>
<th>1055h</th>
<th>1115h</th>
<th>1215h</th>
<th>1315h</th>
</tr>
</thead>
<tbody>
<tr>
<td>CON</td>
<td>Breakfast</td>
<td>Lessons</td>
<td>Lessons</td>
<td>No Snack</td>
<td>Lessons</td>
<td>Lessons</td>
<td>Lunch</td>
</tr>
<tr>
<td>EX</td>
<td>Breakfast</td>
<td>Lessons</td>
<td>Lessons</td>
<td>No Snack</td>
<td>Exercise</td>
<td>Lessons</td>
<td>Lunch</td>
</tr>
<tr>
<td>SK</td>
<td>Breakfast</td>
<td>Lessons</td>
<td>Lessons</td>
<td>Snack</td>
<td>Lessons</td>
<td>Lessons</td>
<td>Lunch</td>
</tr>
<tr>
<td>EXSK</td>
<td>Breakfast</td>
<td>Lessons</td>
<td>Lessons</td>
<td>Snack</td>
<td>Exercise</td>
<td>Lessons</td>
<td>Lunch</td>
</tr>
</tbody>
</table>

Figure 6.1 - Schematic of the protocol for each condition CON = control, EX = exercise, SK = snack, EXSK = exercise and snack

6.3.3 Preliminary visit

The preliminary visit at the research centre consisted of the collection of anthropometric measures, collection of an eating behaviour questionnaire (DEBQ-C, van Strein & Oosterveld, 2008), food selections for the subsequent experimental days, a $\dot{V}O_{2peak}$ test, resting EE measurements and a steady state exercise test.

6.3.3.1 Anthropometric data collection

Stature and sitting stature were measured to the nearest 0.01 m (Seca stadiometer, SECA, Germany) with no shoes. Body weight was measured to the nearest 0.1 kg (Hampel digital scales, Hampel Electronics Co. Taiwan) in light sports clothing and no shoes. Body density was estimated by air displacement plethysmography (BODPOD, Life measurements instruments, Concord USA) in accordance with the methodology of Dempster and Aitkins (1995). Maturation was estimated from peak height velocity using Mirwald and colleagues (2002) equations. Anthropometric characteristics of the participants are displayed in Table 6.2.

6.3.3.2 Resting energy expenditure

Participants wearing a face mask sat quietly in a chair whilst their expired air was collected breath by breath through a respiratory gas analyser (Cortex
Metalyzer 3B, Germany and Metasoft v2.1 software) for a 10 min duration. Oxygen consumption ($\dot{V}O_2$), expired carbon dioxide ($\dot{V}CO_2$) were calculated from the expired air samples.

**6.3.3.3 Exercise tests**

Before commencement of any exercise a heart rate (HR) monitor was fitted to the adolescents (Polar heart rate monitor, Polar Electro, Finland). An incremental ramp test for determination of $\dot{V}O_{2\text{peak}}$ was completed on a cycle ergometer (Lode Excalibur Sport V2, Lode BV, Groningen The Netherlands). Following a 3 min warm-up at 25 W, the work rate was increased continuously by 25 W min$^{-1}$ until volitional exhaustion. 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 (Yelling et al., 2002). Participants were actively encouraged until exhaustion. Expired air samples were collected breath by breath throughout the test. Volitional exhaustion was determined if participants were unable to maintain the pedal cadence (70 ± 5 rpm), in addition to subjective indicators of maximal effort: RER reached a value > 1.1, maximal HR was ≥ 95 % of age-predicted maximum (220 – chronological age), RPE > 9, facial flushing, sweating and rapid shallow breathing. All participants satisfied these criteria. $\dot{V}O_{2\text{peak}}$ 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 given before the steady state exercise commenced. Using the data collected from the $\dot{V}O_{2\text{peak}}$ test, 80 % of gaseous exchange threshold (GET) was calculated for each participant. The work rate required to induce 80 % GET when cycling at 60 RPM was calculated then set on the cycle 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 EE. Average EE per minute when resting and when exercising at 80 % GET was calculated using Péronnet and Massicotte equations (1991). Resting EE was subtracted from exercising EE to yield the net increase in EE per minute from the exercise. The duration required to expend 1 MJ of energy was then calculated for use within the exercising experimental conditions.

6.3.3.4 Food choices

Finally on the preliminary day, participants were asked to select one from the following food choices for each eating occasion for the experimental condition (Table 6.1). Once selections had been made, participants were not able to alter their options between conditions.

Table 6.1 - Meal selection options, one from each category could be chosen.
Experimental conditions

A temporary laboratory was set up in a classroom within the school. Participants arrived at 0800 h following an overnight fast, a prerequisite that was verbally confirmed upon arrival to the tester. 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 the amount could be replicated on the remaining 3 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 schedule for children, PANAS-C) along with the first collection of appetite scores. Appetite scores were collected at 7 time points throughout the testing morning: after breakfast (0835 h), between the 1st and 2nd lesson (0955 h), before break time (1055 h), after break time (1115 h), between the 3rd and 4th lesson (1215 h), before lunch (1315 h) and after lunch (1355 h). Hunger, fullness and prospective consumption were measured on a Visual Analogue Scale (VAS) 100 mm line. 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’. VAS were chosen to measure appetite as they are the most commonly used tool available for use with children (Bellissimo et al. 2007; Bozinovski et al. 2009; Dodd et al., 2008; Moore et al., 2004; Rumbold et al., 2011 and Tamam et al. 2012). VAS have also been validated as a reliable and reproducible tool for measuring pain in children (Shields et al., 2003; McGrath et al., 1996).

Participants were given a 500 mL bottle of water to take with them to lessons with any refills to the bottle being recorded by the participant on 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 (1055-1115 h) 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 researcher an opportunity to ensure the VAS were being recorded at the appropriate 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 - 1033 kJ, carbohydrate ranged from 51-55 %, protein from 11-12 % and fat from 33-37 %. The macronutrient compositions are similar to the average macronutrient requirements for adolescents of this age group (Department of Health, 1991).

Following morning break, those exercising (EX and EXSK conditions) stayed in the classroom, whilst those not exercising returned to their lessons. All exercise sessions ceased 5 minutes before the end of the 3rd lesson (1210 h), therefore depending on the duration of the exercise required to expend 1 MJ of energy, the start time differed accordingly. The exercise duration ranged from 31 - 56 min (mean 44 ± 7 min). The cycling exercise was performed on a Monark 827e friction-braked cycle ergometers within the classroom (Monark Exercise AB, Vansbro, Sweden).

Within the schools normal lunch break (1315-1355 h), participants arrived at the temporary laboratory classroom for their lunch and were given a plate of two 5” pizzas cut into 16 bite sized pieces. Participants were asked to eat until comfortably full. 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 EI could be calculated. Participants ate their pizzas together in their groups of 4,
as this was deemed most like their habitual lunchtime eating environments. Following the final VAS of the condition, participants were able to return in time for afternoon lessons.

6.3.5 Data and statistical analysis

Relative EI was calculated for each condition. By calculating relative EI, the manipulation to the daily EB (+1MJ from the snack or -1 MJ from the exercise) was taken into consideration. Descriptive data are presented as mean and SD unless otherwise stated.

Participant physical and physiological characteristics were compared between sexes using one-way ANOVAs. EI and relative EI were compared between conditions and sex using 2 x 4 mixed model ANOVA. Appetite scores over time were compared between conditions and sex using a 2 x 4 x 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 ANOVAs 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 in the Statistical Package for Social Sciences (version 20.0; SPSS Inc). An alpha level P<0.05 was accepted to indicate statistical significance.
6.4 Results

Participant characteristics are displayed in Table 6.2.

Table 6.2 - Participant physical and physiological characteristics (mean ± SD)

<table>
<thead>
<tr>
<th></th>
<th>Boys (n=20)</th>
<th>Girls (n=18)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>12.9 ± 0.3</td>
<td>13.1 ± 0.2</td>
</tr>
<tr>
<td>Stature (m)</td>
<td>1.58 ± 0.08</td>
<td>1.60 ± 0.05</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>45.9 ± 9.1</td>
<td>47.2 ± 5.4</td>
</tr>
<tr>
<td>BMI (kg/m^2)</td>
<td>15.3 ± 2.3</td>
<td>18.4 ± 2.1</td>
</tr>
<tr>
<td>Body Fat (%)</td>
<td>14.8 ± 7.3</td>
<td>16.5 ± 3.5</td>
</tr>
<tr>
<td>Estimated maturity status from PHV (y)</td>
<td>-0.99 ± 0.58 *</td>
<td>1.03 ± 0.32</td>
</tr>
<tr>
<td>VO\textsubscript{2}peak (mL·kg\textsuperscript{-1}·min\textsuperscript{-1})</td>
<td>49.8 ± 10.5 *</td>
<td>39.7 ± 5.5</td>
</tr>
<tr>
<td>Emotional eating</td>
<td>1.31 ± 0.56</td>
<td>1.35 ± 0.56</td>
</tr>
<tr>
<td>Restrained eating</td>
<td>1.75 ± 0.57</td>
<td>1.80 ± 0.53</td>
</tr>
<tr>
<td>External eating</td>
<td>2.01 ± 0.55</td>
<td>1.95 ± 0.41</td>
</tr>
</tbody>
</table>

* denotes a significant differences between sexes (P<0.05); Peak height velocity (PHV)

6.4.1 Energy intake

Mean ± SE for lunch EI for both sexes over the four conditions, is displayed in Figure 6.2. There were no significant differences between conditions (F (2.446,88.045) 1.602, P=0.202), sex (F (1,36) 2.76, P=0.105) or interaction between condition*sex (F (2.446,88.045) 0.601, P=0.583).
6.4.2 Relative energy intake

Mean ± SE for relative EI for both sexes over the four conditions, are displayed in Figure 6.3. There was a significant difference between conditions (F(2.446,88.045) 11.581, P<0.001). However, there were no significant differences between sex (F(1,36) 2.76, P=0.105) nor interaction between condition*sex (F(2.446,88.045) 0.601, P=0.583). Post hoc analysis indicated relative EI was significantly higher in the CON, SK and EXSK when compared to EX condition (mean ± SE increase 0.8 ± 0.3 MJ, 1.5 ± 0.2 MJ, and 0.8 ± 0.2 MJ).
6.4.3 Water intake

Mean ± SE for water intake over the four conditions, are displayed in Figure 6.4. 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 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 when compared to CON and SK ($P<0.001$). There was also a significant increase in water intake in the EXSK condition when compared to CON and SK ($P<0.001$). There were no significant differences for water intake between CON and SK and between EX and EXSK ($P>0.05$).
Figure 6.4 - Water intake between conditions split for sex (mean ± SE). CON = control, EX = exercise, SK = snack, EXSK = exercise and snack. Boys n = 20, Girls n = 18. * denotes a significant difference to CON (P<0.001) # denotes a significant difference to SK (P<0.001).

6.4.4 Appetite – hunger

Mean ratings of hunger are depicted in Figure 6.5a (boys) and 6.5b (girls). A significant effect of time (F(3.9,140.2) 272.48, P<0.001), condition (F(3,108) 14.32, P<0.001) and condition*time interaction (F(10.2,367.61) 4711.33, P<0.001) were found. There were no significant differences between sexes (P=0.722) or the interaction of condition*sex (P=0.182), time*sex (P=0.718), condition*time*sex (P=0.132). Post hoc analysis indicated hunger was significantly higher in CON compared to SK and EXSK (P<0.001). Hunger was also significantly higher in EX compared to SK and EXSK (P<0.005). However, between each time point in the boys, hunger was only significantly higher in CON and EX conditions when compared to the SK and EXSK at the time point 1115 h (P<0.001). At time point 1215 h hunger was significantly higher in the CON compared to SK (P=0.044) and for EX compared to SK and EXSK (P=0.036 and P=0.030). In the girls,
hunger was significantly higher in the CON and EX condition compared to the SK and EXSK at time point 1115h (P<0.001). At time point 1215 h hunger was significantly higher in the CON compared to SK (P<0.001) and between EX and SK (P=0.001). Finally at time point 1315 h, hunger was significantly higher in the CON compared to SK (P=0.037).

Figure 6.5 - Mean (± SE) visual analogue scale (VAS) for expressions of hunger in boys (6.5a, n=20) and girls (6.5b, n=18) for each condition. CON = control, EX = exercise, SK = snack, EXSK = exercise and snack. Very hungry = 100. Light shaded rectangle, eating occasion; dark shaded rectangle, exercise bout * denotes a significant differences for CON and EX compared to SK and EXSK (P<0.001). # denotes a significant difference for CON compared to SK and for EX compared to SK and EXSK (P<0.05). § denotes a significant difference for CON and EX compared to SK (P<0.002).
6.4.5 Appetite – fullness

Mean ratings of fullness are depicted in Figure 6.6a (boys) and 6.6b (girls). A significant effect of time ($F_{(3.99,143.48)} = 292.95, P<0.001$), condition ($F_{(3,108)} = 15.48, P<0.001$) and condition*time interaction ($F_{(9.91,356.88)} = 4364.74, P<0.001$) were found. There were no significant differences between sexes ($P=0.340$) or the interaction of condition*sex ($P=0.285$), time*sex ($P=0.582$), condition*time*sex ($P=0.565$). Post hoc analysis indicated fullness was significantly lower in CON compared to SK and EXSK ($P<0.001$). Fullness was also significantly lower in EX compared to SK and EXSK ($P=0.001$). However, between each time point in the boys, fullness was only significantly lower in CON and EX conditions when compared to the SK and EXSK at the time point 1115 h ($P<0.001$). Feelings of fullness at 1215 h in the CON and EX condition were significantly lower than SK ($P=0.004$, $P=0.005$) (but not EXSK, $P=0.170$ and $P=0.127$). In the girls, fullness was significantly lower in the CON and EX condition compared to the SK and EXSK at the time points 1115 h ($P<0.001$) and 1215 h ($P<0.002$). At the time point 1315 h, fullness was significantly lower in the CON compared to SK ($P=0.044$) and EXSK ($P=0.001$) only.
Figure 6.6 - Mean (± SE) visual analogue scale (VAS) for expressions of fullness in boys (6.6a, n=20) and girls (6.6b, n=18) for each condition. CON = control, EX = exercise, SK = snack, EXSK = exercise and snack. Very full = 100. Light shaded rectangle, eating occasion; dark shaded rectangle, exercise bout. * denotes a significant difference for CON and EX compared to SK and EXSK (P<0.002). ♯ denotes a significant difference for CON and EX compared to SK (P<0.006). § denotes a significant difference between CON compared to SK and EXSK (P<0.05).

6.4.6 Appetite – prospective consumption

Mean ratings of prospective consumption are depicted in Figure 6.7a (boys) and 6.7b (girls). A significant effect of time ($F_{(3.90,140.30)}$ 288.02, $P<0.001$), condition ($F_{(3,108)}$ 11.35, $P<0.001$) and condition*time interaction ($F_{(9.78,351.99)}$ 3249.09, $P<0.001$) were found. There were no significant differences between sexes ($P=0.467$) or the interaction of condition*sex ($P=0.105$), time*sex ($P=0.586$), condition*time*sex ($P=0.283$). Post hoc analysis indicated prospective consumption was significantly higher in CON compared to SK and EXSK ($P<0.005$). Prospective consumption was also significantly higher in EX compared to SK and EXSK ($P<0.02$). However, between each time point in the boys, prospective consumption was only significantly higher in CON and EX conditions when compared to the SK ($P<0.001$ and $P<0.001$) and EXSK ($P<0.001$ and $P<0.001$) at the time point 1115 h. Feelings of prospective consumption at 1215 h in the CON and EX condition were significantly higher.
than SK (P=0.010 and P=0.002) and EX was significantly lower than EXSK (P=0.017). In the girls, prospective consumption was significantly higher in the CON and EX condition compared to the SK (P=0.003 and P=0.030) and EXSK (P=0.001 and P=0.014) at the time point 1115 h. At 1215 h CON and EX were significantly higher than SK (P=0.004 and P=0.013).

Figure 6.7 - Mean (± SE) visual analogue scale (VAS) for expressions of prospective consumption in boys (6.7a, n=20) and girls (6.7b, n=18) for each condition. CON = control, EX = exercise, SK = snack, EXSK = exercise and snack. Lots and lots = 100. Light shaded rectangle, eating occasion; dark shaded rectangle, exercise bout. * denotes a significant difference for CON and EX compared to SK and EXSL (P<0.03). # denotes a significant differences for CON and EX compared to SK (P<0.014). § denotes a significant difference between EX and EXSK (P=0.017).

6.4.7 Eating behaviour
There were no significant correlations between eating behaviours (emotional, restrained and external) to EI or relative EI for the boys. A significant moderate and positive correlation was found for the girls between emotional eating and EI in the EXSK condition ($r=0.536$, $P=0.022$), external eating and EI in the CON condition ($r=0.635$, $P=0.005$) and EXSK condition ($r=0.620$, $P=0.006$).

6.4.8 Daily emotion

There were no significant correlations between either the positive or negative affect score correlated to EI for boys ($P>0.05$). There was a significant but weak correlation between the positive ($r=0.258$, $P=0.029$) but not negative ($r=0.078$, $P=0.512$) affect score for EI with the girls.

6.5 Discussion

The primary aim of this study was to investigate whether an imposed bout of moderate intensity exercise or a mid-morning snack or both would impact acute EI and/or appetite. 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 to 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 first hypothesis regarding acute changes following the EX condition would be rejected for both EI and relative EI. The second hypothesis regarding acute changes to EI following the SK condition would be accepted for relative EI. Finally, the third hypothesis regarding acute changes to EI following the EXSK condition would be 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 hunger and prospective consumption were significantly higher whilst fullness was significantly lower in the CON and EX conditions when compared to the SK and EXSK conditions, there were no significant differences between CON and EX nor between SK and EXSK. Therefore, all hypotheses relating to appetite are accepted. In contrast to previous studies, which have used a laboratory setting, this is the first time such a study, using relative accurate methods to measure EI and EE, has been taken into the habitual environment of the school, thus increasing the external validity of these findings.

### 6.5.1 Energy intake

The findings from the present study indicate 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 EI and EE (EXSK, +1 MJ/ -1 MJ) when compared to a control condition (CON, 0 MJ). Observing no significant differences for EI following the EXSK compared to 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 or was not of a high enough intensity, as a similar duration of netball exercise which expended 1.4 ± 0.2 MJ was found to significantly increase EI compared to a control condition (Rumbold et al., 2011). Similarly, potentially the snack given may not have been of a big enough size (1 MJ) to alter acute EI for the lunchtime meal significantly. However, the quantity
given (10-15 % of daily recommended intake Department of Health) would be deemed a generously sized snack.

6.5.2 Relative energy intake

Based on results from the relative EI analysis, if an imposed negative energy balance were an aim to help maintain body weight, then increasing daily EE would be recommended. Since 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 to all other conditions.

Surprisingly, relative EI was not significantly higher in the SK condition when compared to the CON or EXSK conditions, i.e. the addition of the snack did not result in an acute positive energy balance as might have been suggested. Interestingly, Muthayya et al. (2007) have demonstrated improved memory performance in children following the consumption of a mid-morning snack. Therefore, the removal of a mid-morning snack is not recommended as a method to create an energy deficit as not only is relative EI unaffected by the consumption of a mid-morning snack, cognitive ability could also be impaired.

6.5.3 Water intake

Water intake was not a key variable within this study, however it was important to monitor the intake as increases in water consumption prior to a meal has been shown to reduce EI (Flood et al., 2006; DellaValle et al., 2005). Water intake was significantly higher for both the EX and EXSK conditions when compared to the CON and SK conditions. The increase in water intake did not appear to reduce EI, as suggested by Flood et al. (2006) and DellaValle et al. (2005), as no significant differences for EI between conditions were found.
Water intake was most likely increased in the EX and EXSK conditions due to the imposed exercise bout triggering a natural thirst response to rehydrate.

6.5.4 Appetite

Unsurprisingly, feelings of appetite changed throughout the test period with participants becoming increasingly hungry, less full and having an increased desire to eat as the morning progressed for each condition. Similarly as expected, the control and exercise conditions had increased hunger and prospective consumption scores and decreased fullness scores compared to the snack and exercise plus snack conditions, where the mid-morning snack suppressed hunger and prospective consumption and increased fullness. Interestingly, the change in appetite observed following the snack was acute and despite the earlier eating occasion from the snack, appetite had returned to match scores from the control and exercise conditions immediately prior to lunch for the boys. For the girls, appetite had returned to match the other conditions for all appetite scores except for hunger and fullness between CON and SK and fullness between CON and EXSK. All participants were primarily rating their hunger, feelings of emptiness and desire to eat immediately prior to lunch the same between conditions. This may go some way towards explaining why there were no significant differences for EI between conditions.

As the school day has a strict structure, which the children are used to, time is an important factor. Observing a similar rating of appetite between conditions immediately prior to lunch could be more related with the children associating this particular time as being lunchtime and subsequently associating that with hunger. This is a hypothesis that would need testing in an environment where knowing what the time was would not be permitted.
6.5.5 Sex differences

Contrary to the adult (Thompson et al., 1988; Pomerleau et al., 2004; King & Blundell, 1995 and King et al., 1996) and paediatric (Bozinovski et al., 2009) literature where sex differences have been found for appetite following exercise, no sex differences were found between the adolescents in this study. Previous published literature has indicated suppression in appetite following predominantly high intensity exercise approximately 68-70 % $\dot{V}O_{2max}$ (Thompson et al., 1988; Pomerleau et al., 2004; King & Blundell, 1995 and King et al., 1996) or exercise at VT for paediatrics (Bozinovski et al., 2009). Therefore, it may have been that the exercise intensity prescribed in this study of 80 % of GET; where GET is approximately 45-60 % of $\dot{V}O_{2max}$ (Jones & Poole, 2005), was not of a sufficiently high enough intensity to suppress appetite.

6.5.6 Eating behaviour and daily emotion

Large inter-subject variability for EI between conditions within similar experimental settings have previously been observed in both the adult (Finlayson et al., 2009; Finlayson et al., 2011 and Unick et al., 2010) and paediatric (Moore et al., 2004) literature. Within our study, EI ranged between participants from 2.2 MJ to 12.1 MJ for the lunchtime meal, both in the CON condition. Factors which 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 to EI with the boys. However, significant positive correlations were found with the 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. The data collected in the present study fails to provide a rationale as to the reasoning behind EI increasing in the control and combined exercise and snack conditions allied with increased emotional and external eating behaviours in the girls. Further research should be conducted to investigate these relationships. The girls were also found to have a significant positive correlation between EI and their positive affect score, indicating 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 of mood (Warren & Brooks-Gunn, 1989). In particular high levels of estrogen in females have been associated with a more positive mood whilst a lack of estrogen has been associated with a depression and negative affect (Buchanan, Eccles, & Becker, 1992). As estrogen levels change over the course of the menstrual cycle, future research should include a measure of the childrens (if applicable) stage in the menstrual cycle on each experimental day. 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 girls with high emotional eating behaviour scores increasing their EI. 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.

6.5.7 Strengths and Limitations

Similar to the studies reported in chapter 4 and 5, this studies strengths were also its’ robust within subjects’ design over the four conditions, the large participant number used, recruitment of both boys and girls and the use of a one item, and therefore homogenised, meal. A further strength to this study was
its’ increased external validity preforming the data collecting within the habitual environment of the school resulting in a minimum disruption to the children’s regular routine. Finally a further strength was the manipulation to both sides of the energy balance equation within the same study, increasing the knowledge of changes to EI and appetite following both a positive and negative energy manipulation within the same group of adolescent children.

Some limitations to the present study are worth noting. Firstly, 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 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 and therefore may not have met precisely 1 MJ. However, every attempt was made to minimise its effect by approximating 1 MJ of EE, following the exercise bout in both the EX and EXSK conditions, to ensure an energy deficit was induced based on our pilot and steady state trials.

The association between over consumption of highly palatable foods (Yeomans et al., 2004) and the provision of a highly palatable pizza test meal is also a possible limitation to this study. However, pizza test meals have previously been used within similar paediatric research (Bellissimo et al., 2007; Bozinovski et al., 2009 and Tamam et al., 2012) and the provision of a one item homogenised meal prevented any macronutrient satiety hierarchy associated with a mixed meal approach (Westerterp-Plantenga et al., 2009; Veldhorst et al., 2008). 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.

6.6 Conclusion

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. This implies that any imposed changes to acute energy balance over the course of a morning will not significantly alter lunch intake. However, relative EI was significantly lower in the exercise condition suggesting that increasing EE would be more beneficial than removing a mid-morning snack if creating an acute energy deficit was a target for example when supporting weight management.

Although hunger and prospective consumption were suppressed and fullness was increased following a mid-morning snack primarily return to match appetite scores to that of the other conditions immediately prior to the lunch meal. This suggests that any changes to appetite prior to the time point typically known as lunchtime will become obsolete based on the familiarity of hunger 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.
7 Appetite Changes and Perceived Energy Compensation Quantities Following Various Sports: An Age and Sex Comparison

7.1 Abstract

Following periods of increased physical activity, it is not uncommon for exercisers to increase their EI as a reward deemed ‘earnt’ following the exercise. Consumers’ awareness of the energy content within food and expended from exercise has previously been found to be limited. Therefore, the aim of this study was to investigate whether habitual exercisers were able to conceptualise the EE of a 1 h habitual training session into a quantifiable amount of EI in food (chocolate) or drink (sports drink). Fifty adult and 49 children from rugby, netball, swimming, hockey and badminton clubs participated in their regular training session having completed a visual analogue scale (VAS) to measure appetite. Following the training session participants completed a second VAS and were asked to estimate the amount of chocolate and sports drink quantity that could be consumed to exactly match the EE of their training. EI was significantly underestimated irrespective of age, sex or sport, mean estimated EI matched less than 36% of the EE. Following swimming and hockey training, hunger was significantly higher (P<0.05) and prospective consumption was significantly higher following swimming and netball. These findings indicate a necessity to improve nutritional education surrounding the energy costs of exercise relative to the energy contained within foods/drinks.
7.2 Introduction

Increasing daily EE is a common recommendation made by health professionals as a method to promote healthy living and prevent weight gain. Current UK recommendations for healthy living are 30 minutes of physical activity five days per week for adults and 60 minutes of moderate to vigorous intensity physical activity every day for children aged 5-18 y (Department of Health 2011). Yet the prevalence of obesity remains high in both adults and children (Health Survey for England, 2012). Weight loss services (including paediatric services) typically suggest using a combination of increasing EE and decreasing EI as methods to promote weight loss, as these yield more promising results than increasing EE or reducing EI alone (Franz et al., 2007).

As exercise and dietary patterns are closely intertwined, it is not uncommon for energy dense foods to be consumed following periods of physical activity, as a reward that is deemed “earnt” for the exercise performed (Finlayson et al., 2011). Elder and Roberts (2007) concluded that following exercise there is a trend for food perceived pleasantness to increase and therefore food consumption may also increase. Additionally, Finlayson and colleagues (2007) reported individuals who displayed an increased interest (liking, wanting and preference) for images of high fat, sweet foods post-exercise, had smaller reductions in fat mass following a 12-week exercise programme compared to individuals who showed less of an interest to the images post exercise. Furthermore, Dohle and colleagues (2014) reported that regular exercisers (between 1-5 h per week) would reward themselves for being active by consuming additional foods. Similarly, greater increases in food intake following exercise labelled as ‘fat-burning exercise’ compared to the same exercise
labelled as ‘endurance exercise’ have been observed, suggesting a psychological impact of labels on subsequent food intake (Fenzl, Bartsch, & Koenigstorfer, 2014). Fenzl and colleagues (2014) suggested the ‘fat-burning’ label provided an implicit cue to participants that made them overcompensate for the energy expended.

The increase in EI, as a post exercise reward for some individuals, may be in excess of the energy expended from the exercise and may attenuate any impact exercise might have had on weight loss (Finlayson et al., 2011). Hypothetically therefore, from an energy balance theory, it may be more beneficial to not exercise and eat sensibly, than to exercise and overcompensate by making unhealthy choices and/or increasing intake as a reward for performing the exercise.

One of the potential reasons for exercisers’ overcompensation is their lack of knowledge regarding the energy content of food and the EE of the exercise completed. Consumer’s knowledge of the energy content within foods is poorly understood (Block et al., 2013 and Burton, Creyer, Kees, & Huggin, 2006). Block et al. (2013) reported estimations of the energy content of meals purchased following a visit to fast food chains, were significantly underestimated by the adults (730 kJ or a 21 % underestimation), adolescents (1080 kJ or 34 % underestimation) and children (730 kJ or 24 % underestimation). Similarly, Burton et al. (2006) reported the actual energy content of the restaurant items (mean energy content 5590 kJ) was nearly twice the value of the estimation of the energy content made by consumers (estimated mean energy content 2900 kJ). Despite the lack of knowledge for the energy content within food, basic nutritional knowledge appears competent (Parmenter, Waller, & Wardle, 2000).
Basic knowledge being defined as an awareness for the recommendations to decrease fat, sugar and salt intake and increase fibre, fruit and vegetable intake.

Quantifying public awareness of the energy demands of exercise and comparing this to the content of the energy in food is an area sparsely investigated. This is surprising considering the well-known link between exercise and reward eating (Finlayson et al., 2011, Dohle et al., 2014). One study as part of a larger investigation, asked health professionals (GPs, life coaches, clinicians, practice nurses etc) to select two from five presented types and quantities of exercise that would equate in energy terms to four different food items (digestive biscuit, pint of beer, McDonalds Big Mac and a roast turkey Christmas dinner) (Cottrell & Chambers, 2013). Of the 135 responders less than a quarter selected the correct two exercises whilst for some of the food items over half failed to select any correct answers. Understanding whether the public’s comprehension is equally as misunderstood as the health professionals in terms of knowledge surrounding the energy expended from exercise and how this equates to the energy consumed in foods, remains to be investigated. If the public’s comprehension is limited, this may help explain the ineffectiveness of exercise-only weight loss interventions (Thorogood et al., 2011) and may suggest education surrounding the energy costs of exercise and the energy contents of food as a better and more appropriate area of weight loss education.

Whether exercisers who regularly participate in recreational sports have an increased awareness of the energy costs of sport and are therefore better able to conceptualise the energy expended into units of energy contained within food
remains to be investigated. Additionally, the effect of an individual's age and sex on their ability to quantify energy is yet to be fully determined.

Therefore, the aim of the present study was to investigate the awareness of energy expended following participation in habitual sporting activities and whether this could be conceptualised into a quantifiable amounts of energy contained within food or drink. The second aim was to determine whether adults or children; males or females were better able to estimate the amount of energy expended in terms of the energy contained within food or drink. The hypotheses were: (1) an expected misunderstanding of the energy expended by exercise combined with a misunderstanding of the energy content within food, therefore inaccurate estimations for the amount of food required to compensate for the energy expended by exercise. (2) Females will estimate more accurately based on a perceived better understanding of nutrition than males, similarly adults will estimate more accurately than children.

7.3 Methods

A total of five local sports clubs (rugby, netball, swimming, hockey and badminton) were approached and 50 adults (18 – 54 y; 23 male) and 49 children (10 – <18 y; 24 male) were recruited. These sports were chosen as they represented both land and water sports, team and individual sports, sports played predominantly by men (rugby) and women (netball) and mixed sex sports (hockey, swimming and badminton) and were sports that are commonly participated in within schools in the UK. These sports were also participated by sports teams that the researchers had existing links to, aiding recruitment and participation in the study. Following institutional ethical approval, all adult
participants provided written informed consent and written consent from parents/caregivers if participants were under 18 years of age. Participants under 18 also signed assent forms.

The researchers coordinated with the coaches of each sports club to ensure training sessions remained unchanged. Data was collected before and after the training session. Each sport trained for a minimum of 1 h per session on a weekday evening between 1800 h and 2130 h. Where sessions were longer, a break to training was given to enable the researchers to capture the end data after 1 h of training.

7.3.1 Measures

Prior to commencement of the training session participants had their stature (Seca 213 Leicester Paediatric Stadiometer, Cranlea, UK) and body mass (Seca 220; Vogel and Halke, Hamburg, Germany) recorded. Participants were fitted with a heart rate (HR) monitor (Polar Team 2 HR Monitors, China) to calculate a predicted EE.

7.3.2 Energy expenditure

HR data was captured per second and averaged for the hour's activity to calculate a predicted EE using the Keytel et al. (2005) equation. Where HR monitors could not be worn (water activities: swimming) EE was calculated using the compendium of physical activities tracking guide for adults (Ainsworth et al., 2011) and youths (Ridley et al., 2008) MET equations. Calculations of EE via the MET method were also performed on the four other land sports for additional analysis of validity of this method of EE calculation against the HR method.
7.3.3 Appetite

Measures of appetite were taken before and after the training session. Using a 100 mm visual analogue scale (VAS), hunger was assessed by the question ‘How hungry are you now?’ anchored on the left by ‘not at all’ and on the right by ‘very hungry’. Fullness was assessed by the question, ‘How full do you feel now?’ anchored on the left by ‘empty’ and right by ‘very full’. Finally, prospective consumption (desire to eat) was assessed using the question ‘How much would you eat right now?’ anchored on the left by ‘nothing’ and on the right by ‘lots and lots’. VAS were chosen to measure appetite as they are the most commonly used tool available for use with children (Bellissimo et al. 2007; Bozinovski et al. 2009; Dodd et al., 2008; Moore et al., 2004; Rumbold et al., 2011 and Tamam et al. 2012). VAS have also been validated as a reliable and reproducible tool for measuring pain in children (Shields et al., 2003; McGrath et al., 1996).

7.3.4 Perceived energy quantities

Following the training session, participants were asked to estimate their perceived EE from their exercise in terms of the amount of food and drink that would be required to replace the energy expended by the completed exercise. Snacks deemed popular after or during sport and were easily recognisable to all participants were selected. The two snack items chosen were a chocolate bar: Cadbury’s Dairy Milk Chocolate (2210 kJ per 100 g) and a sports drink: Orange Lucozade Sport (585 kJ per 100 mL). All participants were asked the same question:
“You have just expended energy during your training session, how much chocolate and sports drink (asked separately) do you think you need to eat/drink to replace the energy you have just used from your training session?”

Participants were provided with visual cues to help estimation of these items but no further information was given. For the chocolate, individual squares of chocolate were broken up from a 45 g chocolate bar and arranged on a white board as one individual square, two squares, and so on up to six squares (a whole bar) and then a pile of chocolate squares (15 squares). Visual cues for the sports drink came from a ½ bottle (250 mL), presented in the bottle and also in a Pyrex measuring jug, a whole bottle (500 mL) and four bottles of sports drink (presented in a 2 L bottle). Without being able to examine any energy guidelines or information on the packaging, participants were asked to estimate and record their perceived energy quantity that would match the energy deficit created by the training session. Recording was performed away from other participants to avoid any peer influence or discussion. Answers could be given in grammes or number of squares for the chocolate and as millilitres or fractions of a bottle for the sports drink. Estimated EI quantities were then converted into kJ by the researchers and compared against the participants predicted EE. The same two researchers conducted all the data collection to minimise influence of researchers’ non-verbal and subconscious cues.

7.3.5 Statistical analysis

Descriptive data are presented as mean ±SD unless otherwise stated. Participant characteristics and EE for sports (calculated both by the HR and MET method) were compared between sports using a one-way ANOVA. A one-way ANOVA was also used to investigate any significant differences between
sports for EE (calculated both by the HR and MET method). A repeated measures ANOVA was used to compare predicted EE from the HR method with the predicted EE from the MET method between sports (excluding swimming where HR data was not available).

A one-way ANOVA was used to calculate any significant differences in estimations of EI from both the chocolate and sports drink between sports. Paired t-tests were used to compare estimates of EI (chocolate and sports drink) against predicted EE (HR and MET method).

The difference between the estimated EI (chocolate and sports drink, in kJ) was calculated from the predicted EE (from both HR and MET, in kJ) and expressed as a percentage of accuracy, where 100% would indicate their estimate matched exactly the EE. These values were then compared against sport and sex using multiple two-way ANOVAs.

Pearson’s correlations were calculated between age and the difference between estimated EI quantities and predicted EE (both HR and MET) split for sex.

The participants’ data was grouped for age and then using a repeated measures ANOVA, individual appetite scores (hunger, fullness and prospective consumption) were compared over time (before and after) between the sports. Significant differences within the ANOVAs 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 in the Statistical Package for Social Sciences (version 20.0; SPSS Inc). An alpha level P<0.05 was accepted to indicate statistical significance.
7.4 Results

The average age of the children was 15.2 y with a range from 10.8 – 17.8 y whilst the average age of the adults was 31.0 y with a range from 18.1 to 54.6 y. Participant characteristics are displayed in Table 7.1. The ANOVA analysis of participant characteristics (grouped for age) indicated that both rugby players (P=0.008) and badminton players (P=0.035) were significantly taller than swimmers. Rugby players were significantly heavier than netball players (P=0.004), swimmers (P=0.002) and badminton players (P=0.04). Consequently the BMI of rugby players was significantly higher than netball players (P=0.036) and badminton players (P=0.006). Badminton players were also significantly younger than both hockey players (P=0.011) and swimmers (P=0.048).

Table 7.1 - Participant characteristics (mean ± SD)

<table>
<thead>
<tr>
<th>Sport</th>
<th>N</th>
<th>Age (years)</th>
<th>Stature (cm)</th>
<th>Body mass (kg)</th>
<th>BMI (kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rugby</td>
<td>Adult</td>
<td>M = 10</td>
<td>23.3 ± 4.6</td>
<td>177.5 ± 4.7</td>
<td>85.5 ± 14.3</td>
</tr>
<tr>
<td></td>
<td>Child</td>
<td>M = 10</td>
<td>16.1 ± 0.5</td>
<td>170.5 ± 17.0</td>
<td>67.0 ± 8.7</td>
</tr>
<tr>
<td>Netball</td>
<td>Adult</td>
<td>F = 10</td>
<td>23.4 ± 5.4</td>
<td>166.9 ± 3.7</td>
<td>63.1 ± 6.7</td>
</tr>
<tr>
<td></td>
<td>Child</td>
<td>F = 8</td>
<td>16.3 ± 0.5</td>
<td>165.8 ± 6.2</td>
<td>55.4 ± 5.1</td>
</tr>
<tr>
<td>Swimming</td>
<td>Adult</td>
<td>M = 5; F = 5</td>
<td>43.0 ± 10.4</td>
<td>168.5 ± 10.3</td>
<td>68.4 ± 13.4</td>
</tr>
<tr>
<td></td>
<td>Child</td>
<td>M = 3; F = 7</td>
<td>13.0 ± 1.6</td>
<td>157.4 ± 9.9</td>
<td>49.5 ± 9.1</td>
</tr>
<tr>
<td>Hockey</td>
<td>Adult</td>
<td>M = 2; F = 11</td>
<td>37.0 ± 12.1</td>
<td>172.0 ± 6.6</td>
<td>72.6 ± 15.7</td>
</tr>
<tr>
<td></td>
<td>Child</td>
<td>F = 7</td>
<td>15.9 ± 0.9</td>
<td>163.6 ± 6.6</td>
<td>59.3 ± 8.2</td>
</tr>
<tr>
<td>Badminton</td>
<td>Adult</td>
<td>M = 6; F = 1</td>
<td>24.2 ± 11.5</td>
<td>179.1 ± 7.2</td>
<td>74.7 ± 9.6</td>
</tr>
<tr>
<td></td>
<td>Child</td>
<td>M = 11; F = 3</td>
<td>15.0 ± 1.4</td>
<td>169.0 ± 11.5</td>
<td>57.7 ± 15.3</td>
</tr>
</tbody>
</table>

N = number of participants: M = males; F = female

7.4.1 Predicted energy expenditure

Predicted EE from both the HR and MET method following 1 h sports play are displayed in Figure 1. There was a significant difference between the methods used to predict EE (F(1,69) 15.6, P<0.001) and also an interaction between
methods*sport ($F_{(3,69)} = 7.01, P<0.001$). Post hoc analysis indicated the HR method yielded a significantly higher ($P<0.001$) value for EE than the MET method (mean difference 326 kJ). When assessed per sports, the HR method had higher values for EE that then MET method for rugby ($P<0.007$, mean difference 431 kJ) and badminton ($P<0.001$, mean difference 802 kJ). There were no significant differences between the methods for predicting EE for netball ($P=0.319$) and hockey players ($P=0.538$).

The EE from rugby players was significantly higher ($P<0.001$) than netball (+704 kJ), hockey (+1014 kJ) and badminton (+663 kJ) players irrespective of method used to predict EE. Badminton players also expended significantly more energy ($P=0.018$) than hockey players (+351 kJ) when EE was calculated from the HR method ($P<0.001$), although this was not significant calculated using the MET method ($P=1.00$).

![Graph showing energy expenditure](image)

**Figure 7.1** - Predicted energy expenditure from both the heart rate (HR) and MET method and estimated EI from both the chocolate and sports drinks for all participants in all sports (mean ± SE). * denotes a significant difference between methods of predicting energy expenditure. Both the chocolate estimation and the sports drink estimation were significantly less than the predicted energy expended from both the HR and MET method (significance not shown).
7.4.2 Estimated energy intake

Estimations of EI quantities from both the chocolate \( F(4,98) 2.17, P=0.078 \) and sports drinks \( F(4,98) 1.89, P=0.119 \) did not differ significantly between sports (Figure 7.1). EI was significantly underestimated (regardless of the method for calculated EE) for both chocolate (HR underestimation 1907 kJ, \( P<0.001 \); MET underestimation 1564 kJ, \( P<0.001 \)) and sports drink (HR underestimation 2251 kJ, \( P<0.001 \); MET underestimation 1923 kJ, \( P<0.001 \)).

Percentages of accuracy are presented in Table 7.2 where 100 % would indicate an exact match between the predicted EE and the estimated intake quantity.

<table>
<thead>
<tr>
<th>Method for calculating EE</th>
<th>Estimations in Chocolate</th>
<th>Estimations in Sports Drink</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HR</td>
<td>MET</td>
</tr>
<tr>
<td>Rugby</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adult</td>
<td>40 ± 75 %</td>
<td>48 ± 87 %</td>
</tr>
<tr>
<td>Child</td>
<td>41 ± 25 %</td>
<td>46 ± 29 %</td>
</tr>
<tr>
<td>Netball</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adult</td>
<td>21 ± 17 %</td>
<td>23 ± 12 %</td>
</tr>
<tr>
<td>Child</td>
<td>47 ± 24 %</td>
<td>46 ± 23 %</td>
</tr>
<tr>
<td>Swimming</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adult</td>
<td>21 ± 11 %</td>
<td></td>
</tr>
<tr>
<td>Child</td>
<td>48 ± 21 %</td>
<td></td>
</tr>
<tr>
<td>Hockey</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adult</td>
<td>19 ± 10 %</td>
<td>17 ± 9 %</td>
</tr>
<tr>
<td>Child</td>
<td>31 ± 16 %</td>
<td>38 ± 25 %</td>
</tr>
<tr>
<td>Badminton</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adult</td>
<td>17 ± 10 %</td>
<td>26 ± 15 %</td>
</tr>
<tr>
<td>Child</td>
<td>37 ± 43 %</td>
<td>51 ± 46 %</td>
</tr>
</tbody>
</table>

HR = Heart Rate, MET = Metabolic equivalent, EE = Energy Expenditure

From the percentage accuracy in chocolate, no significant differences from either the HR or MET methods were found respectively between sport \( F(3,72) \)
0.390, P=0.761), (F(4,98) 0.380, P=0.823); sex (F(1,72) 0.583, P=0.448), (F(1,98) 0.074, P=0.786) nor an interaction of sport*sex (F(1,72) 0.073, P=0.788), (F(2,98) 0.845, P=0.433).

From the percentage accuracy in sports drink against EE calculated from the HR method, there was a significant difference between sex (F(1,72) 6.715, P=0.012). However there were no significant differences between sports (F(3,72) 1.947, P=0.130) nor an interaction of sport*sex (F(1,72) 0.372, P=0.544). Post hoc analysis indicated the males estimated significantly better with 24 % accuracy compared to the females at 17 %. Percentage accuracy for the sports drink against the MET predictions of EE indicated no significant differences between sport (F(4,98) 0.547 P=0.701) and sex (F(1,98) 0.087 P=0.768). However, there was a significant interaction between sport*sex (F(2,98) 3.296, P=0.041). Post hoc analysis indicated no specific differences between sex and the different sports.

Correlations between age and percentage accuracy for females showed a significant negative correlation between age and HR chocolate (r=-0.455, P=0.005) and MET chocolate (r=-0.545, P<0.001). There were no significant correlations (P>0.05) for age and females from the HR sports drink (r=0.075) or MET sports drink (r=-0.215). For males, there were no significant correlations to age and percentage accuracy for either method of predicting EE (-0.172 < r > 0.093, P>0.05).

### 7.4.3 Appetite

Feelings of hunger and prospective consumption were significantly higher following the training session when compared to before (hunger: F(1,94) 19.0, P<0.001; prospective consumption F(1,94) 17.1, P<0.001) whilst fullness was
significantly lower ($F_{(1,94)}$ 29.4, $P<0.001$). There was also a significant interaction for sports*time for hunger and prospective consumption, (respectively: $F_{(4,94)}$ 3.42, $P=0.012$ and $F_{(4,94)}$ 2.90, 42, $P=0.026$) but not fullness ($P=0.153$). Post hoc pairwise comparisons indicated that both swimmers and hockey players felt significantly hungrier (mean increase 32 mm and 17 mm respectively) following the training session ($P<0.05$). Whilst swimmers and netball players had an increased desire to eat following training (mean increase 22 mm and 14 mm respectively) when compared to before ($P<0.05$). Appetite scores when compared between sexes indicated no significant differences ($P>0.05$) either before or after training.

Figure 7.2 - Visual analogue scores (VAS) for hunger (mean ± SE) before and after the training session. 0 = not at all, 100 = very hungry. * denotes a significant difference between before and after training.
Figure 7.3 - Visual analogue scores (VAS) for prospective consumption (mean ± SE) before and after the training session. 0 = nothing, 100 = lots and lots. * denotes a significant difference between before and after training.

Figure 7.4 - Visual analogue scores (VAS) for fullness (mean ± SE) before and after the training session. 0 = empty, 100 = very full. * denotes a significant difference between before and after training.
7.5 Discussion

The present study is the first to have measured the awareness of energy expended following participation in habitual sporting activities and whether this could be conceptualised into a quantifiable amounts of energy contained within food or drink. The primary findings were that all sports players significantly underestimated the energy quantity required from food and drink to replace the energy expended from their sport, the first hypothesis is therefore accepted. Young females were better able to estimate the energy quantity than older females, whereas age had no impact on males. There were no significant differences for the amount estimated between sexes; the second hypothesis is therefore rejected. These findings highlight the need to increase education surrounding the amount of energy expended from sports and the energy contained within food.

7.5.1 Estimated energy intake

The estimated quantity of EI relative to the energy expended from 1 h training was significantly underestimated irrespective of sport (mean EI estimated met less than 36 % of the energy expended). These findings provide evidence that amateur athletes have a very limited awareness about the energy utilised when participating in their habitual sport and the quantity of EI required to compensate for the energy expended. It was encouraging that the majority of participants were underestimating the intake quantity as opposed to overestimating. Only three of the 99 participants over-estimated the intake quantity (two for chocolate and one for sports drink) following their training sessions. However, through conversation with primarily the female participants, many of them commented on how they would opt to eat a whole bar of
chocolate (~995 kJ) after training as opposed to the few squares they were estimating they had expended (female estimation for chocolate quantity ~662 kJ). However, even if they were to consume a whole bar of chocolate as a reward following their training session, this would still be less than the females’ average EE of ~2300 kJ. Thus, future studies could aim to investigate actual EI post training sessions as opposed to a hypothetical estimation.

Sex had no influence on the accuracy of the estimated chocolate or sports drink. Previous studies have reported females, when compared to males, have a better nutritional knowledge (Parmenter et al., 2000) and increased awareness surrounding food (Davy, Benes, & Driskell, 2006). Therefore suggesting that females would be able to more accurately determine the EI required to match their EE from the exercise than males. Surprisingly, our results did not support this hypothesis as no effect of sex on EI estimations was observed. Davey et al. (2006) suggests the increased awareness surrounding food observed in females is due to an increased likelihood of females to diet. Therefore, it is possible that within our cohort the females use exercise as a means to control their weight, opposed to dieting and therefore, had not developed the increased awareness of food apparent with frequent dieters (Davey et al., 2006). Taking a measure of nutritional knowledge in similar future studies may aid the interpretation of results.

The age of females influenced our results. In the present study, younger females were better able to estimate their energy requirements compared to the adult females. Government initiatives surrounding healthy eating are more commonly targeting younger children such as ‘change 4 life’ (DoH) and ‘healthy eating week’ (British Nutrition Foundation). Young females may therefore have more nutritional knowledge, due to these initiatives surrounding diet and healthy
living. However, as these initiatives are also aimed at the young males, who were not significantly more accurate in their estimations than the older males; a more likely explanation as to why the younger females estimated more accurately could be based on their EE from training being smaller. There were no significant differences between sports for estimations of energy requirements (i.e. all sports players estimated similar quantities of food/drink). When the percentage estimation difference was calculated between EE and energy estimated, the differences were much smaller for younger females compared to the older females as the younger females expended less energy from their training sessions.

7.5.2 Appetite

Contradictory to the review by Elder and Roberts (2007) who stated hunger is suppressed or eating is delayed following exercise, our study indicated hunger and prospective consumption increased and fullness decreased following the training session when compared to the start of the session. However, although all sports showed this trend, the change in appetite was only significant for hunger in swimmers and hockey players and desire to eat (prospective consumption) in swimmers and netball players. Sadoul et al. (2014) showed that a change in VAS score of ≥ 15-25 mm is needed to correspond with a significant change in subsequent EI. In accordance with the findings by Sadoul et al. (2014) the netball players’ change in prospective consumption (14 mm) would not have been large enough to alter EI.

Compared to pre training, swimming stimulated hunger and prospective consumption the most of all the sports investigated following the training session. However, as swimmers are advised not to eat within an hour prior to training and their before training mean appetite scores were lower for hunger
and prospective consumption and higher for fullness than any of the other sports, this finding may not be surprising. An increase in hunger and prospective consumption and a decrease in fullness following swimming is in contradiction however, to observations by King, Wasse, and Stensel (2011) who report a biphasic appetite response: an inhibition to appetite during and immediately following training and a later stimulation to appetite in the subsequent hours, following 60 min swimming. However, King et al. (2011) recruited individuals who were habitually active, but not competitive or regular swimmers, as opposed to the regular swimmers recruited within our study. This observation therefore implies that changes in appetite following swimming exercise may be dependent on the habituation to the sport of the population groups studied. Participants habituation to sport impacting on appetite is not a new notion. Harrington and colleagues (2013) found those with habitually high activity related EE expressed attenuated appetite changes compared to habitually low activity related EE who expressed amplified changes in appetite following a bout of exercise.

Exercise intensity has been suggested as a key variable that may alter appetite responses post-exercise. Most commonly, increasing intensities of exercise are more likely to suppress appetite (Thompson et al., 1988; King et al., 1994; King & Blundell, 1995; King et al., 1996; Westerterp-Plantenga et al., 1997). As the training sessions in the present study were left to be conducted as normal, thus ensuring the external validity of the study, exercise intensities of each sport were not controlled for. This difference in exercise intensity makes comparisons between sports for appetites potentially imbalanced if the sports teams were in fact training at different intensities. However, as there were no significant differences for EE between netball, hockey, badminton, and swimming, these
sports could be compared based on expended energy. Rugby players expended significantly more energy suggesting they were working harder than the other sports. However, as the rugby players (a sport that requires a heavier build) were significantly heavier than the others sports and both methods used to calculate EE incorporated body weight. Potentially therefore, the higher EE from the rugby players may likely be attributed to their higher body weights as opposed to an higher exercise intensity of the session. As the literature shows appetite scores are more likely to be suppressed following high intensity exercise (Thompson et al., 1988; King et al., 1994; King & Blundell, 1995; King et al., 1996; Westerterp-Plantenga et al., 1997), and the rugby players did not report any significant changes to their appetite following training, it is more likely that the intensities between sports were similar, and the rugby players increased EE was based on their body size and not an increase in intensity.

7.5.3 Strengths and Limitations

Strengths to this study include the large participant cohort recruited to participate and the representation of varied sports commonly participated within the UK by both adults and children. A further strength would also be the large age range over which both the adults and children were recruited offering a diverse representation of the understandings of energy within the population.

A limitation to this study is the method used to predict EE. Using the HR and MET method to capture EE ensured data could be collected within one testing visit with minimal disruption to the training sessions, therefore maintaining the ecological validity as much as possible. However, even taking into consideration Keytel and colleagues (2005) predicted bias of their equation of 6.27 ± 9.65 kJ/min against actual EE, our findings of participants underestimations of
energy quantities would still be an acceptable conclusion as the underestimations were so large (1907-2251 kJ). A second visit would have revealed the purpose of the study and lead to possible contamination of the participants in discussing the estimated chocolate and sports drink quantities.

A second limitation to this study was whether the significant underestimations of the energy required to compensate for the energy expended from the training session was due to the participants poor understanding of the energy expended from their training session, a poor understanding of the energy contained within foods or a combination of the two. Asking the participants to estimate their EE as a numerical unit of energy may have established a more detailed understanding of the participants' appreciation of energy costs.

A third limitation was the lack of control over the timing and type of evening meal each participant consumed before training, or even if they did eat before training. This may have impacted the appetite results. It is therefore suggested that future research should control or at least have some measure of the timing and type of evening meal consumed prior to training. It is also proposed that future research should also include measures of socio-economic status and educational levels as these have previously been found to impact upon nutritional knowledge (Parmenter et al., 2000).

Potentially our findings were also subject to the Hawthorne effect, with participants altering their estimations in response to their awareness of the experiment. Therefore, care should be taken with extending these findings to suggest intended actions. Future research should investigate both the action and the knowledge of participants.

7.6 Conclusion
It was shown that amateur athletes in this study have limited awareness about their EE following participation in habitual sporting activities and the quantity of EI required to compensate for the energy expended. Irrespective of age, sex or sport, participants significantly underestimated their EI quantities to compensate for the energy expended following 1 h of training. Appetite scores indicated an increased hunger and prospective consumption and decreased fullness in all sports. However, only swimming (hunger and prospective consumption), hockey (hunger) and netball (prospective consumption) reported significant changes to appetite scores. The implications of these findings show a requirement for improving nutritional education surrounding the energy costs of exercise relative to EI.
8 Unrestrained and restrained sex specific adolescent brain activation differences in the fed and fasted states.

8.1 Abstract

Differences between the sexes in neurocognitive functioning (brain activations) have been observed in the adult literature in both a fed and fasted condition. Similarly, differences in brain activations for both adult and adolescent females between those with restrained and unrestrained eating behaviour characteristics have also been observed. Therefore the aim of the current study was to explore how both sex and dietary restraint impacts brain activations in response to visual food stimuli in a group of young adolescents (12-13 y) in both a fed and fasted condition. Fifteen boys (8 restrained and 7 unrestrained) and 14 girls (6 restrained and unrestrained) viewed images of foods and non-foods in a magnetic resonance scanner whilst functional images of their brains were collected. Both a fed and a fasted condition were completed in a counterbalanced order using a within methods design.

When fasted, regions associated with emotion, self-reflection and reward were significantly more activated when compared to the fed condition. There were no significant increases in brain activation in the fed condition when compared to the fasted. In response to visual food stimuli, the girls indicated 8 regions of significantly greater brain activity compared to 1 region in the boys. These regions of activation in the girls were associated with emotion, self-reflection and memory. Brain regions typically associated with reward (and so linked with highly restrained individuals) were significantly activated in the highly restrained group when fasted but not when fed. Further investigations into both the
implications of these findings and also the evolution of brain activation differences in response to visual food stimuli between different age groups, sexes and dietary restraint are warranted.

8.2 Introduction

Food selection and the quantity of intake can be influenced by pleasant and palatable food stimuli. Whether through the media, on screens, in print or when others are eating, visual food cues are continually presented to individuals. Understanding the integral role the central nervous system plays in response to visual food stimuli, particularly in energy and reward homeostasis, remains important given the high levels of obesity (Health Survey for England, 2012).

The organisation and structure of the brain has been well documented to differ between the sexes (Cahill, 2006) in particular neurocognitive functioning and reward processing. Two studies have directly examined functional brain response differences between the sexes in adults in response to food stimuli. Both studies found females showed stronger responses to visual food stimuli compared to males, although the cerebral regions involved between the two studies were different. The first study found a significant increase in brain activations for the females compared to the males in a region associated with sensor processing (fusiform gyrus) (Uher et al., 2006). Whereas, the second study found significant increases in activations for the females in regions associated with high-level decision making, self–reflection, feelings of hunger and current need status (dorsolateral and inferior lateral orbitofrontal cortex, medial orbitofrontal cortex, and posterior/middle cingulate gyrus) (Killgore & Yurgelun, 2010). Whether young adolescent females, like adult females, express similar increased brain activations in response to food images when
compared to adolescent males, currently remains unknown.

Susceptibility to weight gain differs between individuals (Bouchard, 2007) making any identifiable predictive factor important to public health research. One suggested identifiable variable is dietary restraint. Dietary restraint refers to the conscious restriction of EI for the purpose of weight control. It has been proposed that those with high dietary restraint are at an increased risk of obesity (Stice et al., 2005), binge eating and bulimia nervosa (Burger & Stice, 2011). One area of developing interest aiming to differentiate between restrained and unrestrained eaters is brain activation. Research into brain activation differences between restrained and unrestrained eaters is limited (Coletta et al., 2009; Burger & Stice, 2011). One study found, fed restrained eaters displayed increased activations in brain regions associated with desire for food and reward, whereas fed unrestrained eaters displayed increased activations in brain regions associated with inhibition, termination of a meal and memory (Coletta et al., 2009). A second study found that restrained eaters had hyper-responsivity from food stimuli in regions associated with food reward (Burger & Stice, 2011). These findings correlate well to the theoretical model of hyper-responsiveness of the reward circuitry to food intake in restrained eaters (Davis, Strachen, & Berkson, 2004; Dawe & Loxton, 2004). Whether the differentiation in brain activation patterns associated with dietary restraint has developed by the time of adolescence, therefore, warrants further investigation.

As changes to both the morphology and the function of the brain advance through adolescence (Giedd et al., 1999), it is important to investigate brain activation changes for this population separately to adults. The aim of the current study was therefore to explore how both sex and dietary restraint impact
on brain activations in response to visual food stimuli in a group of young adolescents in both a fed and fasted condition. The hypotheses are therefore (1) an increase in brain activation for the females when compared to the males. (2) an increase in brain activations in regions associated with reward for the restrained eaters when compared to unrestrained eaters.

8.3 Subjects and Methods

8.3.1 Participants

The study was conducted in accordance with the guidelines of the Declaration of Helsinki, the British Association of Sport and Exercise Sciences (BASES) and the British Education Research Association (BERA) and the institutional ethics committee approved all procedures. All participating adolescents provided written informed assent, together with consent from their parents or caregivers. A local secondary school in the South West of England gave permission for the researchers to verbally introduce the study to one hundred and sixty nine 12 – 13 y old adolescents to determine their interest to participate. Participants who expressed an interest in the study were asked to complete the DEBQ-C (van Strien & Oosterveld, 2008). From the restrained eating behaviour scores attained from the DEBQ-C, thirty-two participants were recruited, evenly distributed across sex and opposing restraint eating behaviours. The DEBQ-C provided a continuum value for dietary restraint between 1 (strongly unrestrained) and 3 (highly restrained). Participants scoring between 1.86 and 3 were grouped as restrained eaters and participants scoring between 1 and 1.29 were grouped as unrestrained eaters. Subsequently, one boy and two girls dropped out of the study over: a dislike of the scanner environment (1 boy, 1
girl) and a dislike of eating breakfast (1 girl). As a result, groups consisted of eight restrained boys (R-Boy), seven unrestrained boys (U-Boy), six restrained girls (R-Girl) and eight unrestrained girls (U-Girl).

8.3.2 Study procedure

The study was a randomised crossover-design. On the first visit participants were randomly assigned, in a counterbalanced order, to either the fasted or fed condition, with the reverse condition being completed on their second visit. Following an overnight fast, participants arrived at 0830 h at the MR Center where they verbally confirmed their adherence to the overnight fast before testing procedures began. On visit 1 between 0830 h and 0850 h, the adolescents were visually familiarised to the food images to be presented in the scanner to ensure they were able to identify the foods. If a food was not recognised, time was taken to describe the food to ensure a basic level of familiarity was established. On visit 2 this time was used to collect anthropometric measurements (stature, sitting stature and body mass), which was subsequently used to calculate BMI and peak height velocity (Mirwald et al., 2002). Measures of appetite were taken before the scan, after the scan and at the end of the protocol. Using a 100 mm scale, hunger was assessed by the question ‘How hungry are you now?’ anchored on the left by not at all and on the right by very hungry. Fullness was assessed by the question, ‘How full do you feel now?’ anchored on the left by empty and right by very full. Finally, prospective consumption (desire to eat) was assessed using the question ‘How much would you eat right now?’ anchored on the left by nothing and on the right by lots and lots. VAS were chosen to measure appetite as they are the most commonly used tool available for use with children (Bellissimo et al. 2007; Bozinovski et al. 2009; Dodd et al., 2008; Moore et al., 2004; Rumbold et al.,
2011 and Tamam et al. 2012). VAS have also been validated as a reliable and reproducible tool for measuring pain in children (Shields et al., 2003; McGrath et al., 1996). For the fasted condition, participants entered the scanner at 0850 h after they had completed their first VAS. This scan was completed by 0920 h after which participants were instructed to complete a second VAS, before access to an ad libitum breakfast (a choice of 5 breakfast cereals and milk) following which the final VAS of the protocol was completed. Breakfast intake was weighed covertly (Salter, Electronic Kitchen Scales) and recorded for both conditions. For the fed condition ad libitum access to breakfast was permitted between 0850 h and 0920 h. Before entering the scanner at 0930 h participants completed their first VAS. The scan was finished by 1000 h following which a second VAS was completed, before being offered ad libitum access to breakfast for a second time and completion of the final VAS.

8.3.3 Functional imaging procedure

The adolescents were scanned in a whole body MR scanner (1.5 Tesla, Philips Gyroscan Intera) with an eight element head coil. Within the head coil a mirror was mounted, so participants were able to see a screen at the end of the scanner bed onto which images were projected, whilst their head was in the head coil. During the functional scan, the adolescents were presented in a random order with 60 food pictures (with an even distribution over high and low energy foods) and 30 non-food pictures. Each image was located in the center of the screen on a white background. All images were presented in E-Prime version 2 (Psychology Software Tools Inc, Sharpsburg, USA). The adolescents held a MR-compatible button box in each hand and were instructed to press the button in their left hand if they liked the presented food or right hand if they did not like the food. For nonfood images participants were instructed not to press
either button. Requesting the participants to press the buttons in response to the food pictures ensured their attention was maintained throughout the scan. Each image was projected for 5 s, with a blank screen with a cross hair at the center for fixation presented for 4 s in between each stimulus picture. The task lasted approximately 14 minutes. The assessment of brain activity throughout the image paradigm involved the continuous acquisition of single shot echo-planar dynamic images (EPI) (TR = 3 s, TE = 45 ms, resolution 2.5 x 2.5 x 3.5 mm, 38 contiguous transverse-oblique slices, scan field of view 230 x 230 mm, 64 x 64 within-plane matrix). Once the task was completed a high-resolution T1-weighted anatomical image with a resolution of 0.9 x 0.9 x 0.9 mm was performed.

8.3.4 fMRI data pre-processing

The functional images were analysed using SPM8 (The Welcome Department of Cognitive Neurology, University College London) in MATLAB (Mathworks, inc., Sherborn, MA). Pre-processing steps included slice time correction (corrected to the slice obtained at 50 % of the TR), spatial processing, and warping to the Montreal Neurological Institute template (MNI305). Images were then convolved with a 3D Gaussian filter with an 8 mm full-width-at-half maximum (FWHM). The fMRI data was then analysed based on mass univariate (voxel-by-voxel) testing within the general linear model framework over the whole brain, treating each participant separately and constructing individual maps comparing the differences in responses between the two conditions. Group analysis between conditions (fed and fasted); between sexes (boys and girls) and between eating behaviours (restrained and unrestrained) were subsequently undertaken. The group analysis was performed by combining the individual responses to create a contrast map. Acceptance of
significant brain activations were defined as a region where the difference in signal intensity between variables (condition, sex or eating behaviour) gave rise to a p-value < 0.001, after no corrections had been made for multiple comparisons and the cluster size of the activated region was equal or greater than 10 voxels. Coordinates of significance were transformed into the Talairach coordinate system before being looked up with the Talairach Atlas to gather anatomical location.

8.3.5 Data analysis

Participant characteristics were compared between groups using a one-way ANOVA. VAS for all participants were grouped and compared between conditions over time using a repeated measures ANOVA. EI was compared between conditions for both sex and dietary restraint using a mixed model ANOVA. Any significant differences to the ANOVAs were investigated using post hoc Bonferroni corrected pairwise comparisons. A Greenhouse-Geisser correction factor was applied if Mauchly's test of sphericity was violated. Statistical analyses were conducted in the Statistical Package for Social Sciences (version 20.0; SPSS Inc). A value of P<0.05 was accepted for statistical significance. All data are reported as mean ± SE.

8.4 Results

8.4.1 Participant characteristics

Participant characteristics are presented in Table 8.1. There were no significant differences in age, BMI and maturity between all four participant groups (P>0.05). No significant differences were found between the scores for restraint between the U-Boy and U-Girl groups (P>0.05), however the R-Boys scored
significantly higher on the restraint scale than the R-Girls (P<0.02). As expected, the R-Boys and R-Girls scored significantly higher on the restraint scale compared to the U-Boys and U-Girls (P<0.001). When groups were split based on sex only, no significant differences were found between boys and girls for age, BMI, PHV and restraint scores (P>0.05)

Table 8.1 - Participant characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>R-Boy (n = 8)</th>
<th>U-Boy (n = 7)</th>
<th>R-Girl (n = 6)</th>
<th>U-Girl (n = 8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Restraint score</td>
<td>2.47 ± 0.06</td>
<td>1.16 ± 0.05</td>
<td>2.16 ± 0.11</td>
<td>1.14 ± 0.03</td>
</tr>
<tr>
<td>Age (y)</td>
<td>12.8 ± 0.2</td>
<td>12.9 ± 0.2</td>
<td>12.6 ± 0.1</td>
<td>12.8 ± 0.2</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>19.08 ± 1.11</td>
<td>17.37 ± 0.33</td>
<td>22.48 ± 2.49</td>
<td>19.50 ± 1.39</td>
</tr>
<tr>
<td>Peak Height Velocity (y)</td>
<td>-1.65 ± 0.22</td>
<td>-1.79 ± 0.25</td>
<td>-1.93 ± 0.23</td>
<td>-1.59 ± 0.16</td>
</tr>
</tbody>
</table>

All values are means ± SE. R-Boy, restrained boys; U-Boy unrestrained boys; R-Girl, restrained girls; U-Girl unrestrained girls. \(^1\)Significantly different from U-Boy, R-Girl and U-Girl, P<0.02 \(^2\)Significantly different from U-Boy and R-Girl, P<0.001. \(^3\)Significantly different from R-Boy, U-Boy and U-Girl, P<0.02. \(^4\)Significantly different from R-Boy, R-Girl, P<0.001.

8.4.2 VAS findings

Feelings of hunger (Figure 8.1) and prospective consumption (Figure 8.2) were significantly higher in the fasted condition compared to the fed (F(1,28) 62.4, P<0.001 and F(1,28) 85.0, P<0.001). Feelings of fullness (Figure 8.3) were significantly lower in the fasted condition compared to the fed (F(1,28) 102.7, P<0.001). Hunger, prospective consumption and fullness changed significantly over time (F(2,56) 55.3, P<0.001; F(2,46.24) 62.3, P<0.001 and F(2,56) 69.4, P<0.001). There were also significant interactions between condition*time (hunger: F(2,56) 54.4, P<0.001; prospective consumption: F(2,56) 52.05, P<0.001
and fullness: $F(2,45.32) = 88.8$, $P<0.001$). Post hoc analysis indicated that hunger and prospective consumption were significantly higher and fullness was significantly lower in the fasted condition compared to the fed at the time points before scan and after scan ($P<0.001$). There were no significant differences between conditions for hunger, fullness and prospective consumption for the VAS taken at the end of the visit ($P>0.05$). A significant increase in hunger (11 mm) and prospective consumption (12 mm) between the VAS taken before the scan and after the scan in the fasted condition was found ($P>0.001$). No significant differences were found for fullness between the two time points before and after scan ($P=0.124$) in the fasted condition. A significant decrease ($P<0.001$) was found for hunger and prospective consumption between the time points before scan and end of visit (54 mm and 49 mm) and also the time points after scan and end of visit (65 mm and 61 mm) in the fasted condition. A significant increase ($P<0.001$) was also observed for fullness between before scan and end of visit (66 mm) and between after scan and end of visit (71 mm) for the fasted condition. There were no significant differences between the three time points (before scan, after scan and end of visit) for all appetite scores in the fed condition, except for prospective consumption between the before and after scan time points when there was a significant increase of 11 mm after the scan ($P=0.015$).
Figure 8.1 - Feelings of hunger in both the fed and fasted condition over time. Mean ± SE (n=29). *denotes a significant differences between conditions, P<0.001

Figure 8.2 - Feelings of prospective consumption in both the fed and fasted condition over time. Mean ± SE (n=29). *denotes a significant differences between conditions, P<0.001
Figure 8.3 - Feelings of fullness in both the fed and fasted condition over time. Mean ± SE (n=29). *denotes a significant differences between conditions, P<0.001

8.4.3 Energy intake

Energy intakes for the breakfast meal in the fed and fasted conditions are displayed in Figure 8.4. As a group, intake in the fed condition was significantly higher ($F_{(1,25)}$ 5.987, $P=0.022$) than for the fasted condition. However, there were no significant differences between the sexes ($P>0.05$) or dietary restraint groups ($P>0.05$) for EI. No significant interactions were found between condition*sex*dietary restraint ($P>0.05$).
8.4.4 fMRI findings

The following fMRI findings are presented in Tables 8.1 - 8.6. These findings represent when a region is significantly more activated in one condition compared to another condition (i.e. fed v fasted; boys v girls; restrained v unrestrained). These regions of activation are represented by the Talairach Coordinates (X,Y,Z). The ‘t’ column represents the t-statistic. The cluster extent (voxels) represents the size of the cluster of voxels, which are significantly more activated.

The regions of the brain, together with their coordinates, significantly moderated under the varying conditions (fed and fasted) are presented in Table 8.2. The regions of the brain, together with their coordinates, significantly moderated between sexes (boys and girls) are presented in Table 8.3. The regions of the brain, together with their coordinates, significantly moderated between eating behaviours (restrained and unrestrained) are presented in Table 8.4. A further
level of analysis was then performed; Table 8.5 presents the regions of the brain, together with their coordinates, significantly moderated between the sexes for each condition. Finally Table 8.6 presents the regions of the brain, together with their coordinates, significantly moderated between restrained and unrestrained participants for each condition.

Table 8.2 – Regions of the brain showing significantly increased activation under each condition (fed and fasted). All participants combined (n=29).

<table>
<thead>
<tr>
<th>Brain Regions</th>
<th>Talairach Coordinates</th>
<th>t</th>
<th>Cluster extent (voxels)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fasted to Fed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cingulate Gyrus</td>
<td>-8 -27 35</td>
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<tr>
<td>Anterior Cingulate Gyrus (BA 24)</td>
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<td>-18 -31 38</td>
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<tr>
<td>Premotor cortex (BA 6)</td>
<td>10 -19 51</td>
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<td>61</td>
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<tr>
<td>Parietal Cortex (BA 40)</td>
<td>-59 -51 36</td>
<td>4.52</td>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td>BA, Brodmann Area</td>
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</tbody>
</table>

Table 8.3 - Regions of the brain showing significantly increased activation for the boys (n=15) and girls (n=14); conditions combined.

<table>
<thead>
<tr>
<th>Brain Regions</th>
<th>Talairach Coordinates</th>
<th>t</th>
<th>Cluster extent (voxels)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boys to Girls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thalamus</td>
<td>6 -23 5</td>
<td>4.51</td>
<td>24</td>
</tr>
<tr>
<td>Girls to Boys</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Posterior Cingulate</td>
<td>14 -46 21</td>
<td>3.83</td>
<td>86</td>
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<td>Frontal Cortex (BA 8)</td>
<td>6 49 42</td>
<td>5.08</td>
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<tr>
<td>Parahippocampal Gyrus</td>
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<tr>
<td>Cuneus</td>
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<td>39</td>
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<td>Extrastriate cortex (BA19)</td>
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<td>61</td>
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<tr>
<td>Precunes</td>
<td>14 -52 56</td>
<td>4.77</td>
<td>27</td>
</tr>
<tr>
<td>Parietal cortex (BA 7)</td>
<td>14 -70 37</td>
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<td>88</td>
</tr>
<tr>
<td>Cingulate Gyrus</td>
<td>14 -45 26</td>
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<td>121</td>
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<tr>
<td>BA, Brodmann Area</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 8.4 - Regions of the brain showing significantly increased activation for restrained (n = 14) and unrestrained (n = 15) eaters; conditions combined

<table>
<thead>
<tr>
<th>Brain Regions</th>
<th>Talairach Coordinates</th>
<th>t</th>
<th>Cluster extent (voxels)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Restrained to Unrestrained</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frontal Cortex (BA 9)</td>
<td>42 5 26</td>
<td>3.83</td>
<td>17</td>
</tr>
<tr>
<td><strong>Unrestrained to Restrained</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parietal Cortex (BA 5)</td>
<td>-6 -44 59</td>
<td>5.00</td>
<td>85</td>
</tr>
<tr>
<td>Postcentral Gyrus (BA 3)</td>
<td>26 -30 62</td>
<td>4.01</td>
<td>12</td>
</tr>
</tbody>
</table>

BA, Brodmann Area

Table 8.5 - Regions of the brain showing significantly increased activation for the boys (n=15) and girls (n=14) for each condition (fed and fasted).

<table>
<thead>
<tr>
<th>Brain Regions</th>
<th>Talairach Coordinates</th>
<th>t</th>
<th>Cluster extent (voxels)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Boys to Girls FED</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anterior Cingulate</td>
<td>-4 15 -2</td>
<td>5.10</td>
<td>37</td>
</tr>
<tr>
<td>Putamen</td>
<td>26 -44 10</td>
<td>3.91</td>
<td>70</td>
</tr>
<tr>
<td>Orbitofrontal Cortex (BA 47)</td>
<td>24 25 -13</td>
<td>4.78</td>
<td>32</td>
</tr>
<tr>
<td>Frontal Cortex (BA 8)</td>
<td>26 35 41</td>
<td>4.11</td>
<td>21</td>
</tr>
<tr>
<td>Premotor cortex (BA 6)</td>
<td>32 -3 54</td>
<td>4.06</td>
<td>11</td>
</tr>
<tr>
<td>Orbitofrontal Cortex (BA 10)</td>
<td>-8 64 2</td>
<td>4.01</td>
<td>13</td>
</tr>
<tr>
<td>Dorsal Posterior Cingulate Area (BA 31)</td>
<td>10 -55 27</td>
<td>3.95</td>
<td>38</td>
</tr>
<tr>
<td>Cingulate Gyrus</td>
<td>16 -49 25</td>
<td>3.61</td>
<td>38</td>
</tr>
<tr>
<td><strong>Boys to Girls FASTED</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cuneus</td>
<td>-42 -50 6</td>
<td>3.82</td>
<td>10</td>
</tr>
<tr>
<td>Extrastriate cortex (BA19)</td>
<td>-26 -80 26</td>
<td>4.12</td>
<td>66</td>
</tr>
<tr>
<td>Precuneus</td>
<td>16 -68 35</td>
<td>4.40</td>
<td>66</td>
</tr>
<tr>
<td>Parietal Cortex (BA 7)</td>
<td>-14 -40 50</td>
<td>4.12</td>
<td>33</td>
</tr>
<tr>
<td>Frontal Cortex (BA 8)</td>
<td>6 47 42</td>
<td>4.27</td>
<td>24</td>
</tr>
<tr>
<td>Cingulate Gyrus</td>
<td>12 -31 42</td>
<td>4.13</td>
<td>23</td>
</tr>
<tr>
<td>Parietal Cortex (BA 5)</td>
<td>10 -40 55</td>
<td>4.10</td>
<td>17</td>
</tr>
<tr>
<td><strong>Girls to Boys FASTED</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thalamus</td>
<td>6 -23 4</td>
<td>4.42</td>
<td>130</td>
</tr>
<tr>
<td>Parahippocampal Gyrus</td>
<td>-20 -35 2</td>
<td>6.20</td>
<td>64</td>
</tr>
<tr>
<td>Lentiform Nucleus</td>
<td>-10 -4 -3</td>
<td>3.98</td>
<td>15</td>
</tr>
</tbody>
</table>

BA, Brodmann Area
Table 8.6 - Regions of the brain showing significantly increased activation for restrained (n=14) and unrestrained (n=15) eaters for each condition (fed and fasted).

<table>
<thead>
<tr>
<th>Brain Regions</th>
<th>Talairach Coordinates</th>
<th>t</th>
<th>Cluster extent (voxels)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>Y</td>
<td>Z</td>
</tr>
<tr>
<td><strong>Unrestrained to Restrained FED</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parietal cortex (BA 7)</td>
<td>-6</td>
<td>-47</td>
<td>61</td>
</tr>
<tr>
<td>Precuneus</td>
<td>-12</td>
<td>-70</td>
<td>40</td>
</tr>
<tr>
<td>Postcentral Gyrus (BA 3)</td>
<td>34</td>
<td>-30</td>
<td>60</td>
</tr>
<tr>
<td><strong>Restrained to Unrestrained FASTED</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lentiform Nucleus</td>
<td>4</td>
<td>-27</td>
<td>-2</td>
</tr>
<tr>
<td>Orbitofrontal Cortex (BA 10)</td>
<td>32</td>
<td>42</td>
<td>26</td>
</tr>
<tr>
<td>Frontal Cortex (BA 9)</td>
<td>36</td>
<td>37</td>
<td>33</td>
</tr>
<tr>
<td>Postcentral Gyrus (BA 3)</td>
<td>-44</td>
<td>-17</td>
<td>45</td>
</tr>
<tr>
<td>Primary Motor Cortex (BA 4)</td>
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<td>-19</td>
<td>47</td>
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<tr>
<td>Orbitofrontal Cortex (BA 11)</td>
<td>-30</td>
<td>42</td>
<td>-12</td>
</tr>
<tr>
<td>Dorsal Anterior Cingulate (BA 32)</td>
<td>12</td>
<td>36</td>
<td>22</td>
</tr>
</tbody>
</table>

BA, Brodmann Area

8.5 Discussion

The current study assessed the extent of brain activation in response to visual food stimuli in both a fasted and fed condition, between the sexes and also between the dietary restraint characteristics of the participants. This is the first study to have investigated these parameters with a paediatric population. The fasted and fed states were verified through the VAS, which indicated hunger and prospective consumption were significantly increased and fullness was significantly decreased in the fasted condition when compared to the fed. Girls indicated significantly greater activations in 8 regions of the brain compared to only 1 region that was significantly more active in the boys. Therefore the first hypothesis that brain activations for the females will be significantly increased compared to the males is accepted. The regions of the brain that were significantly more activated between the restrained and unrestrained participants were not regions associated with reward. Therefore the second
hypothesis that regions associated with reward will be significantly more activated in the restrained participants is rejected.

8.5.1 Fed v fasted

When all participants were analysed together, no significant increases in brain activity were found when the fed condition was compared to the fasted. However, when the fasted condition was compared to the fed, the following regions were found to be significantly more active in response to viewing food images: regions associated with the value of reward (Brodmann area 24); emotion formation and processing, learning and memory (cingulate gyrus); empathy and self-reflection (Brodmann area 31); emotional working memory (Brodmann area 40) and motor planning and execution (Brodmann area 6). This suggests that when hungry, emotion, self-reflection and reward may all play a part in the processing of visual food stimuli. The significance of Brodmann area 6 is most likely associated with the button pressing part of response setup in the experimental design opposed to the processing of the visual food stimuli. Interestingly the orbital frontal cortex, a region in adults strongly associated with feelings of hunger and desire for food (Füher, Zysset, & Stumvoll, 2008) did not demonstrate an increase in activation in the fasted condition, as might have been expected. However, this is the first time significant neural activation differences, which might underpin food related decision-making, have been demonstrated in young adolescents between a fed and fasted condition.

8.5.2 Sex differences

When differences between the sexes for attitudes towards food are examined, adult females have been shown to be more likely to diet, have an increased
knowledge of food and nutrition and therefore self-assess their dietary habits more regularly than males (Davy et al., 2006). It was therefore perhaps not surprising that the girls when compared to the boys, showed increased activations in regions associated with mental imagery concerning the self (precuneus); self-reflection (Brodmann area 7); emotion formation and processing, learning and memory (cingulate gyrus); memory encoding and retrieval (parahippocampal gyrus); shape recognition (Brodmann area 19); visual processing (cuneus); and planning complex movements (Brodmann area 8). The posterior cingulate cortex was also significantly more active in the girls compared to the boys. This is an area with high connectivity to a large number of control networks in particular being associated with the default mode network; currently there are no clear consensuses about its function (Leech & Sharp, 2014). Conversely, the boys showed a significant increase in activation in the thalamus, a region associated with the relaying of sensory and motor signals to the cerebral cortex and the regulation of consciousness, sleep and alertness. Observing multiple regions of brain activation in the girls when compared to the boys are similar to the findings in adults by Killgore et al. (2010). In their study, males (~46 y) demonstrated no significant increases in neuronal activity whereas adult females (~48 y) exhibited increased activations in the cingulate gyrus, dorsolateral and inferior lateral orbitofrontal cortex and the medial orbitofrontal cortex. This suggests that even at early adolescence, females are demonstrating an increase in brain activations in response to visual food stimuli compared to males.
8.5.2.1 Sex differences when fasted or fed

Reporting findings from the fasted and fed conditions separately by sex, is an alternative approach as previous studies have either reported their findings combined for sex (Goldstone et al., 2009; Holsen et al., 2005) or recruited only female (Coletta et al., 2009; Leidy et al., 2011) or male participants (Führer et al., 2008). Leidy et al. (2011) found adolescent females when fasted displayed increased activations in the brain regions hippocampus, amygdala, anterior cingulate and parahippocampus, relative to the fed condition. Increased activations were also found within the present study in the fasted girls in the parahippocampus (an area associated with memory encoding and retrieval) when compared to the fasted boys, as well as the lentiform nucleus (a region associated with hunger and reinforcement) and the thalamus (relaying of sensory and motor signals). No significant regions of activation in response to visual food stimuli were indicated for the girls when compared to the boys for the fed condition.

Fasted adult males (21 – 29 y) conversely have previously been found to have significantly enhanced brain activity in the left striate and extrastriate cortex, inferior parietal lobe and the orbitofrontal cortices (Führer et al., 2008). The present study similarly found fasted boys to have significantly enhanced brain activity in the superior parietal lobule (self-reflection, somatosensory processing and association) and the extrastriate cortex (shape recognition). In addition to the regions found significantly enhanced for the boys and that matched the findings of Führer et al. (2008), the present study also found significant increased activity in the precuneus (associated with mental imagery concerning the self); the frontal cortex (eye movement); the cingulate gyrus (emotion
formation and processing, learning and memory) and the cunenus (visual processing).

When fed, the boys showed increased activations in areas associated with, emotional activities and food reward (Brodmann area 10 and 47), rational cognitive functions (anterior cingulate), motor skills (putamen), eye movement (Brodmann area 8), motor planning and execution (Brodmann area 6), emotion formation and processing, learning and memory (cingulate gyrus) and empathy and self reflection (Brodmann area 31) compared to the girls. This is in contrast to a significant increase in activation in the left posterior middle temporal gyrus found in fed adult males (Führer et al., 2008).

The results from the present study indicate clear differences for regions of the brain activated between the two sexes over the two conditions. Some of these regions of increased activity match the present literature and some do not. Further investigations as to the implications for these differences between the sexes for brain activity are warranted, as currently this is an area poorly understood. However, it can be conclusively proposed that response to visual food stimuli differs between the sexes in young adolescents.

8.5.3 Dietary restraint

Two previous studies (both in females) have reported brain activation differences between restrained and unrestrained eaters, one with adults (21-23 y) (Coletta et al., 2009) and one with older adolescents (14-17 y) (Burger & Stice, 2011). With the older adolescents, restraint scores were not significantly associated with any areas of increased neuronal activation in response to appetising visual food stimuli (Burger & Stice, 2011). Significant increases in activation of the orbitofrontal cortex (a region associated with reward) was however, found with highly restrained participants when given a taste of
chocolate milkshake, leading the authors to suggest food pictures were a less salient stimuli relative to actual food intake (Burger & Stice, 2011). Comparatively, in response to visual food stimuli, in the present study restrained adolescents (sex combined) demonstrated significant increased activations in the frontal cortex (Brodmann area 9), a region that governs executive functions. Unrestrained adolescents displayed increased activations in regions associated with somatosensory processing and association (Brodmann area 3 and 5). Including male participants in the recruitment of a restrained eating study is an area sparsely investigated in both the adult and paediatric literature, as dietary restraint is more commonly associated with females. However, dietary restraint is not sex specific and is suggested, as with the present study, to be investigated in both sexes. Irrespective of the sensation of hunger or satiation, different regions of the brain are associated with processing visual food stimuli for both restrained and unrestrained eaters. Understanding the implications for these differing regions of brain activation between the two dietary restrained groups is yet to be explored.

8.5.3.1 Dietary restraint when fasted or fed

Restrained eaters are assumed to discount their hunger signals in pursuit of weight loss or maintenance (Herman & Polivy, 1984), thus undermining their ability to generate or recognise normal hunger signals. This observation corroborates our findings of increased activations with the restrained eaters when fasted in regions associated with hunger and reinforcements (lentiform nucleus); self-monitoring of current emotional or somatic states/reward-based decision making (Brodmann area 32), food reward, personal and social behaviour, emotion and decision making (Brodmann area 10 and 11); when compared to unrestrained fasted participants. This suggests that the restrained
eaters are battling with their hunger and desire to control their weight (self-monitoring) in the presence of visually stimulating food cues (food reward). A heightened reward-related response to visual food stimuli could increase the risk of binge eating. There were no significant neuronal activities for the unrestrained group when compared to the restrained group in the fasted condition.

Surprisingly, the unrestrained eaters when fed demonstrated increased activations in regions associated with mental imagery concerning the self (precuneus); self reflection (Brodmann area 7) and somatosensory processing (Brodmann 3) when compared to the restrained eaters. These are regions more typically associated with highly restrained individuals (Burger & Stice, 2011). Although the restraint scores between the unrestrained and restrained groups were significantly different suggesting two distinct groups, the range for the dietary restraint scores for the restrained group (1.89-3) was much larger than ideally desired, particularly when compared to the range of dietary restraint within the unrestrained group (1-1.29). Based on the cohort of individuals invited to the study, highly restrained individuals either did not volunteer to participate or potentially based on the cohorts’ young age, highly restrained eating behaviours might not yet have developed. Having weakly restrained as opposed to strongly restrained individuals could account for the surprising findings for brain activated regions, when compared to the current literature.

8.5.4 Strengths and Limitations

Similar to the studies reported in chapter 4, 5 and 6, this studies strengths were also its’ robust within subjects’ design over the two conditions, the large participant number used and recruitment of both boys and girls.
A limitation to this study would be the use of visual food stimuli as opposed to taste or smell food stimuli, which may have evoked a stronger, or different brain activation response. There are also image resolution limitations associated with a 1.5 T scanner which are inferior to the images that would be generated from a 3 or 7 T scanner.

8.6 Conclusion

In response to visual food stimuli, the girls indicated 8 regions of significantly greater brain activity compared to the boys 1 region. These regions of activation in the girls were associated with emotion, self-reflection and memory. Brain regions typically associated with reward (and so linked with highly restrained individuals) were significantly activated in the highly restrained group when fasted but not when fed. Further investigations into both the implications of these findings and also the evolution of brain activation differences in response to visual food stimuli between different age groups, sexes and dietary restraint are warranted.
9 General Conclusions and Recommendations

In comparison to the adult literature, understanding how exercise alters acute EI and appetite in the paediatric population is substantially under-investigated with only 7 published studies conducted with normal weight children. Therefore the main aim of this thesis was to add to the literature surrounding any changes in EI and appetite following an imposed bout of exercise within children. The key findings from the studies conducted and presented as part of this thesis were as follows. Habitually active girls fail to accurately increase their intake to compensate for an imposed energy deficit, however the variability for energy compensation between participants is substantial (-160 % to 166 %). A bout of MSIE will significantly acutely suppress hunger and prospective consumption and increase fullness in boys but not girls. In a test meal provided 1 h post MSIE, EI is significantly increased in the boys but not girls. Following manipulations to both sides of the energy balance equation; EI is not significantly altered following the addition of a snack or moderate intensity exercise or both compared to a control condition. Whereas, relative EI is however significantly reduced following the moderate intensity exercise. Conceptualisation of the energy expended from 1 h of sporting activity in to units of food and drink is poorly understood, with both adults and children from a multitude of sports significantly underestimating the energy required. Finally, in response to visual food stimuli, significant brain activation differences occur in children, not only between a fasted and fed condition, but also between the sexes and between those with opposing dietary restraint scores.
Overall, innate mechanisms are strongly regulating acute impositions to energy balance on an individual level. However the measures used within this thesis were unable to detected what was governing these individual differences.

### 9.1 Implications of the Findings

The implications of the findings presented within this thesis are as follows:

- The use of a homogenised test meal is suitable for such research within the adolescent population, however it is time-consuming and is preferably a method to be used with short duration studies with a limited sample size.

- The intensity of an imposed bout of exercise is likely to have an impact on acute appetite and EI changes in this age group.

- Should a mixed sex population be recruited to any similarly structured study, findings should be reported sex specifically.

- Eating behaviours appear to have a limited influence on actual EI following a bout of exercise, suggesting measuring eating behaviours in future research should not be a priority within paediatric literature. However, scores of dietary restraint do appear to significantly impact neurological responses to visual food stimuli. The implications of which require further investigation.

- Future policies aiming to increase PA or sports participation in an adolescent population should consider both the intensity of the PA recommended and whether these recommendations need to be sex specific.
• The daily school structure should consider the timings of PA sessions (i.e. PE lessons) and eating opportunities (break and lunch times). As the timing of the PA (or PE) session within the school day may influence EI.

### 9.2 Future Research

In addition to the future research proposed following each study, it would also be suggested that any future work should aim to include a validation study for measuring EI. EI as measured and described throughout this thesis is in accordance with the current literature published. Most often, acute changes in EI following an exercise condition are compared to EI following a control or sedentary condition. Changes in EI following exercise are computed based on the EI from the control condition being ‘energy balanced’. However, if the EI on the control day was high or low for any reason, comparing control EI to the intervention EI is futile. As acknowledged by Thivel et al (2013), sedentary activities may increase EI more so than any exercise activity. Validations for measuring EI in repeated controlled conditions have not been well established in either the adult or paediatric literature. Similarly, validating VAS in children in an environment without ‘time’, to prevent ‘lunch time’ associated changes in appetite, as mentioned previously, should also be considered.

Future research should also aim to focus on trying to establish a variable that accurately correlates to the varying change in EI between participants for each condition. Whether it be a biological, psychological, environmental or social factor, further research is required within the paediatric population.
In conclusion, the findings presented within this thesis have demonstrated original and interesting results regarding how an imposed increase in EE, participants' sex and their eating behaviours may impact EI and appetite. However, in doing so, as with all research there are many more questions still yet to be answered.
10 Appendix

10.1 Visual Analogue Scale

Visual Analogue Scale

Name:                  Date:                  Time:

How hungry are you now?

Not at all         Very Hungry

How full do you feel now?

Empty              Very Full

How much would you eat right now?

Nothing          Lots and Lots
### Dutch Eating Behaviour Questionnaire for Children (DEBQ-C)

**Dutch Eating Behaviour Questionnaire for Children**

**Instruction**
Below you’ll find 20 questions about eating.
Please read each question carefully and tick the answer that suits you best.
Only one answer is allowed. Don’t skip any answer.
There are no incorrect answers; it’s your opinion that counts.

<table>
<thead>
<tr>
<th></th>
<th>Question</th>
<th>No</th>
<th>Sometimes</th>
<th>Yes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Do you feel like eating whenever you see or smell good food?</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>If you feel depressed do you get a desire for food?</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>If you feel lonely do you get a desire for food?</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Do you keep an eye on exactly what you eat?</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Does walking past a candy store make you feel like eating?</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Do you intentionally eat food that helps you lose weight?</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Does watching others eat make you feel like eating too?</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>If you have eaten too much do you eat less than usual the next day?</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Does worrying make you feel like eating?</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Do you find it difficult to stay away from delicious food?</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Do you intentionally eat less to avoid gaining weight?</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>If things go wrong do you get a desire for food?</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Do you feel like eating when you walk past a snack bar or fish and chips stand?</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Have you ever tried not to eat in between meals to lose weight?</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Do you have a desire to eat when you feel restless?</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Have you ever tried to avoid eating after your evening meal to lose weight?</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Do you have a desire for food when you are afraid?</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Do you ever think that food will be fattening or slimming when you eat?</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>If you feel sorry do you feel like eating?</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>If somebody prepares food do you get an appetite?</td>
<td>No</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Dear Parent/Guardian

The Children’s Health and Exercise Research Centre is devoted to research into children’s health and well-being with a focus on how children respond to different exercise challenges. Children cannot be considered “mini adults” as their bodies respond very differently to adults. We are trying to understand these differences so that we can make more accurate recommendations as to what sort of exercise is best for young people as they grow and mature.

We would like to involve your child in a study which will help us understand more about appetite control in young people following high intensity exercise. For this, your child will be required to come to the university on three different occasions from breakfast time to the afternoon (around 1pm). The series of tests is explained in the information letter attached.

If you agree to allow your child to participate in the project could you and your child sign the attached consent form and return it to the head of year 8, Mrs Sarah Lasker as soon as possible. Should you have any further queries, please do not hesitate to contact Mrs Lasker at the School or Assoc. Prof. Craig Williams or Miss Joanna Varley on the contact numbers below.

We would like to extend our appreciation and thanks for your support and cooperation.

Assoc. Prof. Craig Williams  Miss Joanna Varley
(01392) 724890  (01392) 257997

This study has been approved by the Sport and Health Sciences Ethics Committee
10.4 Information Sheet for Parents for the Study Reported in Chapter 7

**Perceived energy compensation requirements following various sporting physical activities, an age comparison**

What are we investigating?
There seems to have been little research in adult’s and children’s perceived energy requirements after exercise. This study will look at children’s and adult’s perception of how much food and drink they will need to replace the energy they have just lost due to exercise. We are studying different sports and age ranges to see if there are any comparisons.

How are we going to find these things out?
Your child will be asked to participate in one training session as normal. The children and adults will have their age, gender, height and weight recorded. Those participating in land based sports will be fitted with a heart rate monitor to measure their physical activity. They will then be asked to complete a scale expressing their appetite and hunger sensations, before carrying on with their normal training session. After they have exercised they will estimate how much of two food items they would need to consume to replace the energy that they have just expended through the exercise. They will also be asked to complete the hunger scale once more. By assessing your child’s perceived energy requirements after their sport we can see whether there are any differences between different sports and age ranges. This could help with research into maintaining energy balance following physical activity.

What if they want to drop out of the study?
Your child can drop out of the study at any time without any negative repercussions with the University or sports club.

What will we do with the results?
All the results we collect will be stored on a computer. No one will be told your child’s results. We will write the study up as a paper and present the group results to other researchers but their information will remain confidential. Only the people who are doing the tests will be able to see their individual information. You are most welcome to request a copy of the results of the project if you wish.

What if I have a question?
If you have any questions please contact Professor Craig Williams (01392 724890), Miss Joanna Varley (01392 257997) or Miss Rebecca Ewen (07581350689) or Email: jlv203@exeter.ac.uk or ree202@exeter.ac.uk

The project has been reviewed and approved by the Ethics Committee of the Sport and Health Science at the University of Exeter.
Dear Parent/Guardian

**Participant Information for Child Participant**

**The role food images has on brain activity in adolescents**

What are we investigating?
This study will look at how images of different foods change brain activity in young adolescents. Investigating this link has not been explored in children before, however the techniques we shall be using have been repeatedly performed by children.

How are we going to find these things out?
We will be using techniques called functional magnetic resonance imaging (fMRI). This technique allows us to take “pictures” of your brain (a bit like an x-ray but with no radiation). When you look at different pictures when in the MRI scanner we get images of how the brain is working. These techniques do not use x-rays or any other potentially harmful radiation, but instead use radio waves (like those for a radio or TV transmission) and a large magnet. For each of the visits we will ask you to come to the University to view images of food whilst in the scanner. You will be provided with breakfast cereal to eat whilst at the University.

Is it safe?
Worldwide millions of people have had MRI scans with no obvious side effects and it has not been found to be harmful in any way.

What tests will you be doing?
You will be asked to participate in 2 test days, for both visits please remember that we would like you not to eat breakfast in the morning until you get to the University. We also ask that you stop eating from 8.30 pm the previous night but you can drink water if you would like. After you have finished the tests, we will provide you with breakfast. Please make sure you are in school by 8 am to be collected to go to the research centre.
On the first day, you will arrive at school at 8 am and be taken to the University research centre. We will take you to our replica scanner that we have built so you can get used to the size and shape of the scanner. The scanner can be noisy so we play similar sounds that you will hear. We will then take you to the real scanner to do the test. The test will last a total of 30 minutes including rest time. Breakfast will be given to you.

For the second day, you will arrive at school at 8 am like for the first day and taken to the University research centre. We will measure your height and weight. You will then be asked to enter the scanner for to do the same tests again that you did for the first day. Breakfast will be given to you.

What do you need to wear?
For all the tests you should wear normal clothes, but please try and avoid items that contain metal in the tops and jumpers. Zips in your trousers are fine.

What foods will you be offered?
The breakfast cereal provided will be lots of recognisable types and brands of breakfast cereal that you can choose from.

**Why do I need to complete a health questionnaire?**
It is important that together with your parent/guardian you fill out the attached health questionnaire as honestly and as accurately as possible. Please provide any relevant medical information particularly allergies to cereals that might affect your ability to take part in the testing. This information will help us in making sure that the risk is minimised for any future illnesses developing during the study.

What if you want to drop out of the study?
You can drop out of the study at any time without any consequences with the University or the School.

What will we do with the results?
All the results we collect will be stored on a computer. No one will be told your individual results. We will write the study up as a paper and present the group results to other researchers but your information will remain confidential. Only the people who are doing the tests will be able to see your individual information. You are most welcome to request a copy of the results of the project if you wish.

What if I have a question?
If you have any questions regarding the study please contact Professor Craig Williams (01392 724890) or Miss Joanna Varley (01392 257997) or email jlv203@exeter.ac.uk and we will be happy to help.

The Ethics Committee of the Sport and Health Sciences has reviewed and approved this project.
Participant Assent Form

The influence on food responses following moderate intensity exercise, a snack or combination in 12-14 y old boys and girls.

To be completed by the child participant:

I have read the information sheet about this project and understand what it is about. Any questions I have about the project have been answered. I know that if I want any more information I can ask for it at any time. I understand that I will be asked to go to the University on the first day, and will take part in 4 experimental days whilst at school. I understand I will be asked to take part in exercise on an exercise bicycle. I also understand that we will be offered by the University breakfast, snacks and lunches on four days.

I know that:
1. taking part in the project is entirely my free choice
2. I can stop taking part in the project at any time without any bad consequences
3. the results collected about me will be kept in secure storage
4. the results of the project may be published but my identity will be a secret.

Signed.................................................................Child Participant

Date....................................................

This study has been approved by the Sport and Health Sciences Ethics Committee
Parent/Guardian Consent Form

The influence on food responses following moderate intensity exercise, a snack or combination in 12-14 y old boys and girls.

To be completed by the Parent/Guardian:

I have read the information sheet concerning this project and understand what it is about. All my questions have been answered to my satisfaction. I understand that I am free to request further information at any stage. I understand that my child will be asked to visit the University on one occasion and take part in prepared sessions whilst at school for the remaining 4 experimental days. I understand that my child will be taking part in exercise testing and will be offered breakfast, snacks and lunches on four occasions, prepared by the University.

I know that:
1. my child's participation in this project is entirely voluntary
2. my child is free to withdraw from the project at any time without disadvantage
3. the raw data on which the results of the project depend will be retained in secure storage
4. the results of the project may be published but my child's anonymity will be preserved.

As your child will be receiving food provided by the University for the breakfast, snack and lunch time meals, please could you let us know whether there are any known foods that your child has any allergies or intolerances to.

My child is allergic/intolerant to the following foods:

..........................................................................................................................................

Signed............................................................................................Parent/Guardian

Date........................................

Emergency contact phone number:

...........................................................................................................................................
10.7 Conference Attendance

Presented at the International Society for Magnetic Resonance in Medicine (ISMRM): Joint Annual Meeting. Milan May 2014. The role of breakfast on cognitive function in adolescents: an fMRI study (a study I collaborated on, therefore not reported within this thesis)

Presented at the Youth Sport Conference. Brunel November 2013. Acute energy intake and appetite responses following high-intensity interval exercise in 12-13 year old boys and girls

Presented at the Nutrition Society: Irish Section meeting. Childhood Nutrition and Obesity: Current status and future challenges, June 2013. Acute energy intake and appetite responses following high-intensity interval exercise in adolescents – for conference abstract see 10.8

British Nutrition Foundation Conference in Physical Activity: the latest on its contribution to energy balance and health, October 2011. Delegate

European Group of Paediatric Work Physiology XXVII Biennial Conference, Sept 2011. Involved in the planning of this conference as our department were the hosts as well as attending as a delegate
Acute energy intake and appetite responses following high-intensity interval exercise in 12–13 year old boys and girls

J. Varley1, M. Moore2 and C. A. Williams1
1Children’s Health and Exercise Research Centre, St Luke’s Campus, University of Exeter, Exeter, EX1 2L, UK and
2School of Health Professionals, Plymouth University, Plymouth, PL6 8BB, UK

Following exercise, gender differences in energy intake (EI) and appetite have been reported in adult literature. High intensity exercise suppresses appetite in males but not females12,20 and significantly increases EI in females but not males14,20. Investigating gender differences in EI and appetite following exercise in the paediatric population has not been performed in normal weight children, and only once in obese adolescents18. Therefore, it is important to distinguish gender effects at a young age as maintaining energy balance post exercise is important for growth.

Twenty boys and 18 girls (12–13 y) participated in this study. In the control condition no exercise was permitted from arrival for breakfast until after lunch had been consumed. The exercise condition involved sprint cycling for 10 s followed by 110 s slow active recovery, repeated 15 times for a total duration of 30 min. Sixty minutes post completion of the exercise an ad libitum lunch was offered and EI was recorded. Lunch consisted of sandwiches and cake offered in excess and with homogenised macronutrient compositions48. Differences in EI at lunch relative to exercise energy expenditure were calculated. Appetite ratings of hunger, fullness and prospective consumption were rated 6 times throughout the day using visual analogue scales45.

There were no significant differences in EI between conditions for either gender (p > 0.05). The mean EI difference between conditions was not representative of individual data. Figure 1a and 1b. EI compensation was not significantly correlated with any anthropometric measures for boys (R² = 0.31, p = 0.64) or girls (R² = 0.16, p = 0.95).

![Figure 1a and 1b. Individual differences for energy intake in MJ on the exercise condition compared to control condition in boys and girls.](image)

Prospective consumption was found to have a significant interaction over time when contrasted between conditions for the boys. The boys expressed a reduction in their desire to eat following exercise, similar to that found in adult males17. Hunger and fullness showed no significant interactions for either gender. High intensity interval exercise reduced the desire to eat in boys but not girls. This reduction did not track into changes of EI for the subsequent meal. This is the first study to report gender differences in appetite following exercise in children and requires further elucidation.

We would like to acknowledge PhD studentship funding from Kellogg Ltd UK.

11 Reference List


