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Review article

Energy regulation in young people

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Abstract
Obesity in young people is now realised as a worldwide crisis of epidemic proportion. The aetiology of this disease suggests a disruption in regulation of energy at the population level, leading to a positive energy balance and excess adiposity. The relative contribution of food intake and physical inactivity remains to be elucidated. Treatment interventions have aimed to create a deficit in energy balance through manipulation of physical activity, behavioural components or, to a lesser extent, dietary modification. Whether such intervention is maintained in the long-term is as yet unclear, however it seems a combination of therapies is optimal. Mindful of a mismatch between energy intake and expenditure, recent work has begun to examine the acute relationship between physical activity and food intake in children. Initial findings suggest a short-term delay in compensation through energy intake for exercise-induced energy expenditure. The overarching study of energy regulation in children and adolescents is clearly multifaceted in nature and variables to be assessed or manipulated require careful consideration. The collection of paediatric physical activity, energy expenditure and food intake data is a time-consuming process, fraught with potential sources of error. Investigators should consider the validity and reliability of these and other issues, alongside the logistics of any proposed study. Despite these areas of concern, recent advances in the field should provide exciting opportunities for future research in paediatric energy regulation on a variety of levels.

Key words: Obesity, children, diet, energy expenditure.

Introduction

Published statistics indicate that 17% of boys and 23.6% of girls in the UK are either overweight or obese (Lobstein et al., 2003), with the trend expected to increase (Sabin et al., 2004) over the next few years. Indeed, it has been predicted that 1 million children in England will be obese by 2010 if no action is taken (NICE, 2006).

The issue of paediatric obesity and associated disease, both during childhood and following into adult life, has been the subject of much recent discussion. It is established that overweight and obesity can pre-dispose adults to cardiovascular disease, diabetes, stroke and certain cancers (Carroll, 1998; Kumanyika et al., 2002). In 2002 the 'Public Health Approaches to the Prevention of Obesity' working group, which is part of the International Obesity Task Force reported that ischaemic heart disease is ranked as the highest global disease burden. Not only that, but worldwide cases of diabetes mellitus in adults are expected to rise to 300 million by 2025. Currently approximately 85% of individuals with diabetes are type II, of whom 90% are overweight or obese (Kumanyika et al., 2002). Childhood overweight and obesity can persist into adult life, increasing susceptibility to such life-threatening conditions, however risk of morbidity from cardiovascular disease and all-cause mortality during adulthood is likely to be increased even when obesity does not persist from childhood (Kiess et al., 2001; Must and Strauss, 1999). Summerbell et al. (2003) report an association between childhood obesity and medical conditions such as poor pulmonary function, advanced growth and early maturity, hepatic steatosis, cholelithiasis and less commonly, the pathological conditions pseudotumor cerebri, sleep apnoea, polycystic ovary disease and orthopaedic complications. The emergence of type II diabetes cases in children is lending even greater concern to the energy intake (EI) and macronutrient selection habits of children, particularly in those presenting with overweight and obesity (Fagot-Campagna et al., 2001).

The contribution of diet and inactivity to overweight and obesity has been investigated in children (Gregory et al., 2000; McGloin et al., 2002; Treuth et al., 1998) but which parameter, or combination of parameters, is responsible for changes in fatness is at present still not clear. Low levels of physical activity in young people have been consistently reported (Twisk, 2007) and these have coincided with an increase in levels of overweight and obesity (Chinn and Rona, 2001). There is currently a greater tendency for children to be driven to school, rather than to walk and many playground activities have been replaced with more sedentary pursuits, such as watching television or playing computer games (Sabin et al., 2004). On the other side of the energy balance equation, cheap, energy dense foods and sugar-containing fizzy drinks are now commonplace, with frequent snacking and fast food replacing regular meals (Sabin et al., 2004).

What is clear, is that the increasing prevalence of obesity in adults and children, suggests a mismatch between EI and energy expenditure (EE) such that many individuals are in a marked positive energy balance for prolonged periods of time, leading to excess adiposity. Although the relative roles of diet and activity in the childhood obesity epidemic still remain to be clarified, it is clear that focus needs to be on both sides of the energy balance equation if this ever-increasing trend is to be abated. In this context, it is also important that the implications of promoting an increase in EE, on subsequent EI, are fully understood. This is particularly important in childhood obesity treatment where exercise is often used as an alternative to dietary intervention since a focus on food restriction may increase the likelihood of eating disorders (Goran et al., 1999). Furthermore, although there appears to be a long-term mismatch between EE and EI, regulation of energy is not well understood for young individuals, with research in its infancy.

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The present review aims to explore the factors associated with disrupted energy regulation in young people. Whilst this will invariably consider the aetiology of overweight and obesity, particular attention will be paid to the special considerations necessary when investigating these factors in children and adolescents.

Determination of overweight and obesity

It is pertinent to begin by looking closely at how scientists and health professionals have quantified a chronic disruption of energy balance. Although body fat levels and distribution are important predictors for health-risk factors, for purposes of defining overweight and obesity trends, BMI [mass (kg) / stature (m^2)] has been recommended as being the most appropriate measurement (Reilly et al., 1999; Wells, 2000) in young people. This is largely due to the ease of administration, and inexpensive nature of assessing mass and stature, compared to other more direct measurement techniques (Prentice and Jebb, 2001). The BMI method theoretically provides an index of mass, independent of stature (Wells, 2000).

In adults, overweight is generally defined as a BMI of ≥ 25 kg/m^2 and obesity as a BMI of ≥ 30 kg/m^2, these being associated with increased risk to health. Whilst the epidemic nature of excess adiposity in young people is not contested, there has been much debate regarding exactly how paediatric body fat levels should be classified; as yet there are no accepted cut-off points for overweight and obesity. In 1997 the International Obesity Task Force advocated linking the adult BMI cut-off points of 25 kg/m^2 and 30 kg/m^2 to reference centiles in order to elicit child-specific cut-off values (Dietz and Bellizzi, 1999). Cole et al. (2000), used growth survey data from over 97,000 boys and 94,000 girls (0 – 20 y) in Brazil, Great Britain, Hong Kong, the Netherlands, Singapore and the US to develop the current international reference curves (Jebb and Prentice, 2001). The centile curves were constructed using summaries of age-specific curves derived from the median and coefficient of variation of BMI at each age, and also accounted for age dependent skewness in the distribution of BMI (Cole et al., 2000). The seven British reference centiles are spaced two thirds of a *z*-score apart. Overweight and obesity cut-off points throughout childhood are indicated; these corresponding to the adult cut-off point at age 18 y (25 and 30 kg/m^2).

The International Obesity Task Force reference curves have been criticised since they were produced by averaging national data curves of different shapes. Chinn and Rona, (2001) highlight that this results in cut-off points which fail to correspond to any fixed *z*-score for any population. Indeed, when data has been analysed using previously established and recognised cut-off points based on UK data only (Cole et al., 1995), these UK reference points have proved more sensitive, resulting in elevated prevalence data (Chinn and Rona, 2002).

The application of BMI to children and adolescents is problematic since it relies on chronological age and fails to take maturation into account. Since BMI does not describe fat-free mass or fat mass, the assumptions inherent in assuming 'overweight and obesity' due to a large mass for stature score, are of particular concern in this population. Specifically, due to differing rates of growth and maturation between young people of similar age, body proportions, frame size, bone mass, and the ratio of lean to fat tissue, are not consistent between individuals at the various age-related BMI reference cut-off points (Livingstone , 2000; Rowland, 2005).

Cut-off points for actual adiposity, as opposed to inferred adiposity, have been suggested in the past. Dwyer and Blizzard (1996), collected data on variables associated with dyslipoproteinemia, hypertension, BMI and skinfold thickness in a group (n = 1834) of 9 and 15 year old children. They proposed a cut-off point of 30% body fat for girls and 20% body fat for boys to define obesity. Whilst these definitions may be used as a guide, they have not been widely accepted and used in epidemiological studies. This is probably due, at least in part, to the impractical nature of using body composition techniques to assess large groups. It is also important to appreciate that assessment of skinfold thickness is susceptible to a variety of random and systematic sources of error (Livingstone, 2000), not least the potential for inter-investigator variability in measurement.

It is important to highlight the recent advances in alternative paediatric body composition assessment methods, which will impact on some fields of research. These include dual-energy X-ray absorptiometry (DEXA), magnetic resonance imaging (MRI) and the BodPod (Dempster and Aitkins, 1995) method of air displacement plethysmography. The latter technique has demonstrated good validity and precision for fat mass and fat-free in young people and provides a practical alternative to the 'gold standard' hydrostatic weighing procedure (Dewit et al., 2000; Fields and Goran, 2000). Obviously the method of choice will depend on the nature of the investigation and feasibility of assessment.

It should be realised that whilst BMI has provided a solution in terms of defining overweight and obesity and therefore the risk of subsequent disease, it is the level of excess adipose tissue which is linked to co-morbid conditions, rather than the presence of excess weight per se (Prentice and Jebb, 2001). Until a replacement procedure is developed for classification of adiposity and the link with health problems, then BMI should be employed and the limitations appreciated. Where possible, both %body fat and BMI data should be presented for participants.

Causes of overweight and obesity

Dietary factors

The National Food Survey showed that British households are actually consuming less energy than in the 1970's (Ministry of Agriculture, Fisheries and Food, 1940 – 1994), but it has been suggested that there is a relationship between obesity and high dietary-fat intakes (Prentice and Jebb, 1995). The Department of Health estimated average requirements (EARs) for energy in children (7 – 10 years), are 8.24 MJ and 7.28 MJ for boys and girls respectively, rising to 9.27 MJ and 7.72 MJ for 11 – 14 year old boys and girls. These values increase to 10.60 MJ and 8.10 MJ for adult males and females respectively (19 – 50 years) (Department of Health, 1991).

The National Diet and Nutrition Survey (NDNS, Gregory et al., 2000) commissioned by the Department of Health and the former Ministry of Agriculture, Fisheries and Food, is the most recent source of data collected (in 1997) regarding the energy and nutrient intake of 4 – 18 year old children in the UK (n = 1701). Seven-day weighed records of food intake indicated that mean daily EI in 7 – 10 year old boys and girls were 7.47 MJ and 6.72 MJ respectively, rising to 8.28 MJ and 7.03 MJ in 11 – 14 year old boys and girls. These intake values are clearly lower than the nationally recommended estimated average requirements (EAR, Department of Health, 1991), suggesting that over-consumption in EI terms is not singly responsible for the positive energy balance underlying the overweight and obesity epidemic in the UK. Interestingly, preliminary feasibility work for this study (Smithers et al., 1998) indicated that EI data were lower than both EARs *and* estimates of EE obtained by the doubly labelled water method across most sex and age groups. This suggests some degree of under-reporting, most prominent among older girls.

Recently, nutrition and paediatric specialists looking to ascribe macronutrient choice, rather than energy intake per se, as contributing to the obesity epidemic have highlighted the energy density of foods. Energy density is related to the energy value of a volume of food, quantified as g/kcal (Rolls and Roe, 2002). If a food possesses a high water content (such as many fruit and vegetables), for example, then the energy value will be relatively low making the energy density (g/kcal) low. Foods of high energy density include those high in sugar, snack foods such as chocolate and sweets, along with high fat foods.

The NDNS showed mean total fat intake as being close to that recommended by the Department of Health, although some concern is warranted over apparently elevated saturated fatty acid consumption due to associated adverse health conditions. Taken as a whole, fat consumption alone does not appear to provide an obvious answer to the energy balance paradox.

Data from the NDNS suggest a decrease in total carbohydrate intake for girls and boys aged 10 - 11 years and a significant decrease at 14 - 15 years, when compared to earlier national survey data collected in 1983 (Department of Health, 1989). The majority of dietary carbohydrate is recommended to come from starch, intrinsic and milk sugars; extrinsic sugars such as sucrose, being associated with dental decay, obesity, diabetes (Bender, 2002). The survey reports that sugar, preserves and confectionary comprised 11% of total carbohydrate intake in 7-10 year old boys and girls, and 12 and 11% respectively in 11-14 year olds. Sugar-containing drinks provided 10% of total carbohydrate intake in the same groups with 5-6% coming from biscuits, buns, cakes and pastries. Sugar, preserves, confectionary and drinks were the main sources of non-milk extrinsic sugar consumption in all groups. The current DRV for non-milk extrinsic sugars is 11%, this was exceeded by both boys (16.7%) and girls (16.4%). More than one quarter of food energy was obtained from non-milk extrinsic sugars by the upper 2.5 percentile (Gregory et al., 2000). Finally, fruit and vegetable intake was low (fruit and nuts 2-4%, vegetables excluding potatoes 2-3% of daily carbohydrate intake) across all groups (Gregory et al., 2000).

From the amount of data presented in the National Diet and Nutrition Survey, it seems as though the food choices of young people, rather than total calorie intake per se, is a cause for concern; specifically energy density of foods consumed, in terms of fat and sugar. Smaller-scale investigations support this notion, linking fat intake to body fatness (McGloin et al., 2002; Tucker et al., 1997). Other factors, such as parental adiposity (Maffeis et al., 1998) have also been linked with paediatric adiposity. In the context of the present review, it seems clear that macronutrient selection is a likely co-variant in the disruption of energy balance and thus the long-term aetiology of obesity.

It has been suggested that high-fat diets will lead to over-consumption of energy (Rolls and Hammer, 1995) due to the high energy density and low satiety of high fat foods (Blundell et al., 1993). This theory is supported by the assertion that fluctuations in carbohydrate and protein intake can be compensated for by changes in substrate oxidation, but according to Flatt, (1995) fat stores are not similarly regulated since fat oxidation is determined to an extent by the body's carbohydrate economy. This may lead to an imbalance between fat intake and oxidation, possibly contributing to obesity. Unfortunately, there are few studies investigating this in young people and those that have are mostly cross-sectional and findings are equivocal.

Physical inactivity

Hours engaged in recreational physical activity outside of school seem to have been replaced with watching television or playing computer games (Hoos et al., 2003). A reduction in time spent engaged in physically active day to day tasks will lead to a reduced EE and subsequent alteration in daily energy balance. Over a prolonged period of time, this will inevitably lead to accumulation of excess adiposity if food intake is not similarly down regulated.

Recently, the hypothesis that a lack of physical activity may play an important role in attainment and maintenance of childhood obesity has been more widely accepted, although results from studies are equivocal (Trost et al., 2001). The assessment tools described earlier have been used in studies investigating the existence of a relationship between inactivity and overweight or obesity. Some of the more tightly-controlled investigations will be discussed here.

Gillis and colleagues (2002) demonstrated significantly more hours spent engaged in activities of a light intensity nature for obese children (n = 91) versus non-obese (n = 90) and also significantly fewer hours engaged in activities of a moderate and hard intensity, estimated in METS. Using a seven day uniaxial accelerometer and self-report-based protocol, Trost et al. (2001) reported significantly lower total physical activity counts per day and significantly fewer minutes participating in moderate (3 - 5.9 METS) and vigorous (≥ 6 METS) activity in 54 obese versus 133 non-obese children (11.4 ± 0.6 years). A similar relationship was observed by Maffeis et al. (1997), who found a positive association between physical inactivity and adiposity in 28 free-living 9 year old boys, using the FLEX heart rate (HR) as a critical point below which inactivity was assumed. Conversely, using whole-room respiration calorimetry and doubly labelled water, Treuth et al. (1998) reported no differences in physical activity between overweight and non-overweight 7-10 year old girls (n = 24) after adjustment for fat-free mass. Earlier work (Goran et al., 1997) from the same laboratory supports these findings.

The majority of research findings do, however, appear to demonstrate a link between inactivity and adiposity. Unfortunately no study has yet investigated physical inactivity on a large scale, again mainly due to the methodological constraints. Despite this, physical inactivity is strongly believed to have a causal role in the development and maintenance of childhood obesity (Scottish Intercollegiate Guidelines Network, 2003).

Before embarking on a discussion of obesity treatment methods, it is pertinent to consider the methods, which tend to be used to assess such parameters in young people. Whether the aim of the investigation is to provide epidemiological data, observe long-term regulation of energy in response to a behavioural (such as dietary or physical activity) intervention, or explore the acute regulation of EE and EI, measures should include body composition, BMI, food intake and physical activity or EE as a minimum. Indeed a major problem in interpreting data from the available intervention studies is the variation in protocols used to assess these important factors.

Measurement of physical activity and, energy expenditure in young people

Commonly, physical activity is quantified in terms of physical activity level (PAL) or number of multiple of resting metabolic rate (MET). PAL expresses energy expended over 24 h as a multiple of basal metabolic rate (BMR) (Bender, 2002); one MET is used to define resting EE and activities are assigned multiples of this.

Physical activity data-collection methods appropriate to paediatric study can be placed into different categories: self-report and proxy report, observation, motion sensor monitoring, and finally physiological analyses (Harro and Riddoch 2000, p.78). Self-reported measures such as physical activity questionnaires and interviews can, in some instances are translated into a quantifiable EE. For example the four-by-one day physical activity recall questionnaire devised by Cale (1994) has been validated using HR and observation methods. Unfortunately this is not the case for many self-report questionnaires. A further limitation with recall is the demand placed on the young person to recall specific events.

Pedometers allow accumulation of activity counts, based on vertical movement of an individual. More recently, accelerometers have provided a record of vertical movement (uniaxial), or movement in multiple planes (multiaxial), indicating frequency and intensity of activity (Harro and Riddoch 2000, p.81). There are still inherent limitations with all of these procedures, including limited measurement of planes, and the tools available will overcome these problems to varying degrees.

The choice of technique for estimating EE is dependent on a number of issues such as financial cost and practicality. Studies which have investigated the relationship between EE and EI have used a variety of physiological methods, including doubly labelled water (Westerterp et al., 1992), whole room indirect calorimetry (Horton et al., 1994) and the FLEX HR method (Stubbs et al., 2002a; 2002b).

The doubly labelled water technique is often considered the 'gold standard' in EE measurement and facilitates free-living measurements of EE. The expensive cost, however, makes it unsuitable for frequent use or for large scale epidemiological investigation. In addition, type, intensity, frequency or duration of specific activities cannot be determined. The method involves ingesting a small amount of water containing stable isotopes, hydrogen and oxygen ($^{2}H_2{}^{18}O$). Labelled oxygen is emitted from the body as water and carbon dioxide, with labelled hydrogen emitted as water only. Samples may be obtained from urine and blood samples, with subtraction of hydrogen losses from oxygen losses providing a measure of EE.

Indirect calorimetry involves measurement of carbon dioxide produced and oxygen consumed in order to determine the respiratory exchange ratio. Additionally, assessment of urinary nitrogen excretion will provide an estimate of protein oxidation. Indirect calorimetry may be conducted using a chamber, hood, mask or mouthpiece (Manore and Thompson, 2000) and EE may subsequently be predicted from equations such as the Weir formulae (Weir, 1949). If determined accurately, over 24 hours, the error for estimating EE using a whole room open-circuit indirect calorimeter has been reported as 2% (Emons et al., 1992). Indeed, whole room indirect calorimetry reduces measurement error by facilitating calorimetry measurement over 24 hours. This particular method requires the participant to be present in the calorimeter during measurement, therefore a free-living situation cannot be investigated.

The advantage of estimating EE through HR monitoring, over the other two cited techniques, is practicality. Heart rate watch-style receivers may be worn on the wrist and telemetry straps attached to the chest area. Due to the portable nature of the equipment, assessment may be made of EE in a free-living environment.

Heart rate monitoring is a useful tool for assessment of both physical activity and EE. In some instances, researchers have selected HR thresholds above which activity may be determined, reporting time spent within specific HR bands (Gilliam et al., 1981). Other investigators have used regression to extrapolate relative $\dot{V}O_2$ from HR, facilitating estimation of EE using calculations such as those of Weir (1949). The latter procedure should follow a calibration test involving activities pertinent to those of interest in the investigation. At a low HR, such as at resting, the relationship between HR and oxygen uptake ($\dot{V}O_2$) is less stable. This is most likely due to the decrease observed in stroke volume between the supine and standing position. The resting HR threshold should be determined for each individual during the calibration procedure. According to Ceesay et al. (1989), the threshold can be calculated from the mean of the highest HR during the lowest intensity exercise and the lowest HR obtained during a standing measurement period. Sedentary EE is defined as all the time spent with a HR below the threshold value.

This method is known as the FLEX HR technique and the interested reader is referred to the work of Livingstone and colleagues (1990; 2000) for a thorough examination of paediatric protocol issues. Reasonable validity has been demonstrated against doubly labelled water and whole-body calorimetry, so long as specific 'measurement' of EE on an individual level is not a requirement. For example, it would be unsuitable to report patterns of activity in a single child but would be appropriate on an epidemiological level, or to confirm the impact of an imposed exercise bout.

Measurement of food intake in young people

Techniques of choice for assessing the food intake of individuals are largely dependent on the nature of the investigation. Commonly used methods include the food diary technique whereby estimated or weighed records of foods eaten are self-reported, retrospective 24 hour recall, and food frequency questionnaires. A further prospective approach is to use trained observers to directly record the food intake of individuals.

Underreporting of food intake is an intrinsic problem with self-reported dietary assessment. Indeed, Black (1996) reports that use of the doubly labelled water method has identified self-reported food intakes that cannot habitually represent a sustainable level. This has important implications for studies that have investigated the aetiology of obesity, or the relationship between EE and EI, since many have relied on food diaries.

Further evidence for underreporting has been observed in different population groups (Bandini et al., 1990; Livingstone et al., 1990; 1992). In particular, problems have been identified in girls, obese adolescents and those with a high BMI (Champagne et al., 1998). There is also an effect of age on under-reporting of dietary intake, with a trend towards greater under-reporting with increasing age (Livingstone et al., 1992). In their review concerned with dietary intake measurement in children, Livingstone and Robson (2000) reported that up to 40% of EI in obese adolescents may go unrecorded, compared to 25% in 10 year olds. Reasons for this age-associated trend are likely to include the fact that as individuals get older, they have more control over their food choices and there may be less parental involvement when recording information. A key age has been suggested for 7-10 year olds, whereby novelty and curiosity may play a role in maintaining compliance with dietary reporting (Livingstone and Robson, 2000).

It is clear that caution should be applied when interpreting self-reported records of children and adolescents, since it is likely that the true levels of food consumed will not be reflected. A potential solution to this problem was proposed by Goldberg and colleagues (1991). In order to identify under-reporting in adults, this group identified cut-off points based on a PAL of 1.55. Torun et al. (1996) subsequently reported age and sex-specific cut-offs for children and adolescents. Where group data are to be considered, for example in survey work, these papers should be considered carefully in order to identify errors in reported intake.

An inherent problem in monitoring the food intake of individuals through direct observation is that the presence of the investigator may cause a change in the regular eating behaviour of the subject. Where food intake is to be assessed in response to a stimulus or action such as exercise, so long as foods offered are kept constant across conditions (including a control) then this method is advantageous, eliminating any possibility of under-reporting by the participants. In adults, good agreement has been demonstrated between food intake recorded by observation and EE measured by the doubly labelled water method (Diaz et al., 1992; Prentice et al., 1989). Observation of food intake is generally only feasible on a small scale.

Direct observation has been used in many adult studies where the experimental aim has been to look at effects of exercise upon parameters of food intake (King and Blundell, 1995; Lluch et al., 1998). This has also been the method of choice in paediatric investigations concerned with exercise-induced EI (Dodd, 2005; Moore et al., 2004) and the impact of food pre-loads on subsequent food intake (Hägg et al., 1998, Wilson, 1999). In addition, this method facilitates manipulation of macronutrient content, if desired. Finally, food may be served in an ad libitum fashion, allowing subjects to eat as much as desired and removing any pressure to eat a set meal in its entirety. This process has been used in short-term paediatric investigations (Moore et al., 2004) and provides a strictly controlled environment for food intake.

With such methodological issues in mind, it is pertinent to look at those studies, which have attempted manipulation of these and other variables. The aim has generally been to disrupt a positive energy balance through intervention.

Treatment and prevention of overweight and obesity

Although the health benefits of physical activity have been well established in adults, child benefits are more difficult to ascertain due to the length of time required to observe effects (Hoos et al., 2003). Unfortunately there are few longitudinal studies investigating the effects of one or more intervention strategies in young people either presenting with, or at risk from, obesity. Cross-sectional intervention studies are more apparent in the literature and are becoming more frequent, however longer-term adherence to any intervention measure really needs to be reported in order to assess treatment efficacy fully. Interventions generally take the form of one or more of physical activity manipulation and/or inactivity reduction strategies, behavioural changes through psychological means, or less commonly dietary modification.

To date, much of the more rigorously controlled work, conducted with at least a 6 month follow-up has come from the US (Epstein et al., 1985a; 1985b; 1995; 2000). This series of separate interventions reported efficacy, identified by a reduction in % overweight, for a number of protocols including dietary and behaviour management advice coupled with aerobic exercise (Epstein et al., 1985a), aerobic, lifestyle exercise or callisthenics treatment (Epstein et al., 1985b), and reduced sedentary behaviour (Epstein et al., 1995). More recently, the same group indicated similar efficacy between reduced sedentary behaviours versus increased physical activity (Epstein, 2000).

There is also evidence for the success of alternative approaches such as behavioural therapy (Graves et al., 1988), although other researchers report weight re-gain (Israel et al., 1994) or weight loss similar to control groups (Duffy and Spence, 1993; Warschburger et al., 2001).

A thorough comparison of the cited literature is limited, due different techniques having been employed to constitute a 'behavioural' intervention. The interested reader is referred to the systematic review of Summerbell and colleagues (2003), which utilised rigorous inclusion criteria for studies. The same problem exists in the physical activity intervention literature and consequently drawing firm conclusions concerning efficacy of strategies is not possible at this point in time. It does seem clear, however, that increasing time spent in physical activity habits and/or decreasing that engaged in sedentary pursuits will lead to changes in weight status, at least in the short-term. More passive treatments, such as behavioural therapy involving self-help and other educational measures, also appear successful. Further work is required employing longer-term interventions (with follow-up over a period of years) and frequent maintenance sessions to prolong and maintain any weight loss. Consistent treatment methodologies are also needed to facilitate future comparisons between studies.

A recent proposal by Steinbeck and colleagues (2006) will hopefully go some way to resolving these issues in future childhood overweight and obesity management work. The aim is to develop an international register of randomised controlled trials, enabling eventual prospective meta-analysis using conventional strategies. There are clearly also clinical implications from the present evidence-base, although practical guidelines have only recently been developed. The National Institute for Health and Clinical Excellence (NICE, 2006) has published guidelines for the prevention, identification, assessment and management of overweight and obesity in adults and children for use within the National Health Service in England and Wales. For Scotland, the Scottish Intercollegiate Guidelines Network (SIGN, 2003) provides recommendations for best practice in obesity management, based on current evidence.

Energy expenditure and the drive to eat

Having considered the longer-term regulation of energy in young people, through the imposition of various physical and behavioural interventions, it is prudent to consider the impact of acute manipulations on energy balance. Understanding the relationship between EI and EE is important in order that we may comprehend the regulation of EI and its role in the aetiology of obesity. Clearly, a poor physiological coupling between EE and EI may have a role in the attainment of a positive energy balance and subsequent weight gain.

Blundell et al. (2001) discusses a traditional research perspective, appreciating the 'drive to eat' as having origins as a homeostatic process, responding to fuel utilisation and energy expenditure. According to this perspective, resting metabolic rate may be the basis for this drive, with other components of EE, such as physical activity, also being involved. This physiological need may be translated into a behavioural process through signals involved in fuel utilisation, glucose availability and brain neurotransmitters such as neuropeptide Y and possibly leptin. A detailed review of peripheral mechanisms involved in food intake is provided by Stubbs (1999).

Obviously, when EE is equivalent to EI, an equilibrium state of energy balance will be achieved where weight is stable. The traditional idea of a 'set point' (Mrosovsky and Powley, 1977) by which energy balance is monitored through some negative feedback loop to correct feeding behaviour, has been recently advanced by the discovery of leptin and the development of the lipostat. Readers are referred to a detailed account by Speakman (2003). However the rise in overweight and obesity clearly demonstrates a lack of, or flaw in, such an operational feedback system. Indeed, in order to maintain equilibrium at a higher level of body weight, EI must increase in response to the laying down of tissue.

Exercise-induced EE may account for a large or small proportion of daily EE, dependent on the individual. This component of daily EE may be substantially manipulated, for purposes of training and engagement in sports and other activities, or to elicit weight loss. Similar to the set-point theory, a common-sense viewpoint might presume that an automatic response to exercise-induced EE will be a compensatory increase in EI. However, much of the evidence suggests the existence of a lack of compensatory increase in EI in response to exercise, in other words a loose coupling between EE and EI (King, 1999).

Simply stated, there are numerous sequences involved in the interaction of putative peripheral appetite and food intake signals. It is important to appreciate the problems involved in integrating these systems, quantitatively, in order to establish a single theory of appetite and control of feeding. Similarly, it is impossible to elucidate individual or multiple mechanisms as entirely responsible for any behavioural response. Therefore, experimental models with humans tend to look at feeding and appetite as specific 'behaviours'.

Compensation for manipulation of energy intake and energy expenditure

Whilst the coupling between intake and expenditure has been investigated in adults over the short-term (Hubert et al., 1998; King et al., 1996), at the time of the present work, there is a dearth of studies regarding the compensatory responses of children, in terms of EI or appetite, to an exercise pre-load. It has been reported that short-term experimental studies in adults have found little energy compensation for exercise with no automatic increase in EI, hunger, or the drive to eat (Blundell and King, 1999), suggesting that compensation may not be an automatic response to a manipulation of EE. It seems likely, however, that differences in EI responses to exercise may occur within different population groups. In particular, different EI responses to exercise have been reported within lean individuals, and between lean, overweight and obese adults.

Of those studies that have attempted to investigate appetite in children, the focus has been on the impact of dietary manipulations on subsequent energy intake (Hägg et al, 1998; Wilson, 1991; 1994; 1999). It has, however, previously been documented (Birch and Deysher, 1986) that children may have a larger capacity than adults to compensate for the effects of a missed meal. Experimental work has looked at compensation arising from food pre-loads or energy dense meal accompaniments but is largely limited to pre-school children (Birch et al., 1989; Hägg et al., 1998; Wilson, 1991; 1994; 1999). Hägg et al. (1998) demonstrated in pre-school children that the introduction of a 1.5% fat milk drink with lunch, versus a water drink with lunch, caused an increase in total lunch EI of 17%. Similar findings were also reported by Wilson (1991; 1994). These data together suggest that food intake is not immediately down-regulated in order to compensate for increased energy consumption from a drink. Interestingly, in the study of Hägg and colleagues (1998) a significant reduction in energy intake obtained just from food was observed for girls offered a meal plus milk drink compared to when offered a meal plus water drink. It is possible, therefore, that some degree of compensation was occurring in this group, but not sufficient to prevent an overall elevation in EI.

This lack of compensation appears to extend to 90 minutes and has been documented in both adults and children (Anderson, 1995; Wilson, 1999). It has been subsequently suggested that after 90 minutes a child's compensatory responses are somehow interfered with and that when food is offered 20-60 minutes following a sucrose pre-load compensation is likely to occur (Anderson, 1995, Wilson, 1999). There is evidence however, that regulation of food intake during this time interval may be dependent to a degree, on macronutrient composition (Zandstra et al., 2000).

Whether this apparent short-term lack of compensatory down-regulation is observed where EE is manipulated, as opposed to EI, is unclear where children are concerned. There is a need for intervention work to examine food intake responses to exercise in young people in order for comparisons to be drawn against the wealth of adult-based literature. Studies should be of a high methodological quality in order to minimise error resulting from under-reporting of EI. Quantification of exercise, and prediction of EE should also be controlled as accurately as possible.

To date, two such investigations have been conducted with young people (Dodd, 2005; Moore et al., 2004). The first study in this series (Moore et al., 2004) observed ad libitum EI at lunch and dinner in 19 girls (10.0 ± 0.6 years), following laboratory-based cycling designed to elicit a total 1.5 MJ EE at 50 % and 75 % of peak $\dot{V}O_2$. The major finding from this work was that despite a significantly higher EE in both exercise conditions, compared to a sedentary condition, there was no evidence of compensation for the energy cost of the exercise through an increase in EI (lunch + dinner). This is illustrated in terms of relative EI in Figure 1. Such an apparent lack of compensation is perhaps contrary to the popular belief that exercise will cause an immediate increase in hunger, and thus EI.

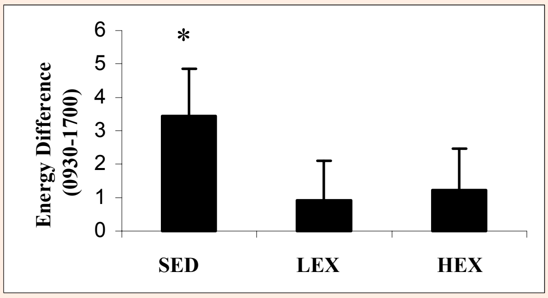

Figure 1. Energy difference (ad libitum energy intake minus energy expenditure, MJ) for 9-10 y girls (mean ± SD) following one day low intensity cycling (LEX) and high intensity cycling (HEX) challenges. SED (sedentary condition) energy difference was significantly different to that of both exercise intensities ($p < 0.01$).

Subsequently a similar high intensity exercise protocol, but with a longer period of follow-up, found no differences in individual total daily or 5 day total EI for either lean or overweight girls (n = 12, 11.5 ± 0.4 years) (Dodd, 2005). This was despite a trend towards an elevated daily EI for the overweight group. Surprisingly, self-reported visual analogue scales indicated that overweight girls felt significantly hungrier and less full immediately post- exercise versus pre-exercise. This is in conflict with much of the adult literature. Possibly children are less sensitive to the physiological inhibition of appetite following high intensity exercise. Alternatively, the nature of self-reported appetite data may have led the overweight girls to simply think that they should feel more hungry following exercise. This issue requires investigation. Importantly, for the overweight group, the apparent lack of compensation for exercise-induced EE has implications for the role of exercise in weight management, at least in the short-term. On the other hand, lean girls (and indeed boys) must compensate at some point, in order to restore energy balance. In fact, physiological demands of growth and maturation dictate that young people must necessarily be in a slight positive energy balance.

There are many other avenues for further research in this field, including exploration of medium and long-term responses of similar groups in order to elucidate a point at which equilibrium is restored for EE and EI. Also important is the study of sex differences, as well as the effect of age and maturational stage on EI responses to exercise.

Conclusions

Undoubtedly, the study of energy regulation in young people is at present an area of particular interest for health professionals and scientists alike. The consensus that obesity has reached epidemic proportions has led to further examination of the evidence-base on a number of levels. Firstly, the underlying causes of a disruption in energy balance have to be addressed appropriately, via extension of the present epidemiological survey data. Secondly, it is hopeful that the implementation of rigorous and comparable protocols to examine weight management interventions should eventually influence further clinical guidelines. Thirdly, the measures used to assess variables of paramount importance, such as body composition, food intake, physical activity and EE, need to be fully appreciated in order to provide robust data for the evidence-base. Finally, the acute relationship between physical activity and food intake requires extensive study in order to elucidate the behavioural responses to imposed exercise, as well as the types of activity and level of food intake monitoring necessary for successful intervention.

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Key points

- Physical activity appears to be an effective intervention in paediatric weight-management, however future studies need to be extended over the longer-term employing consistent protocols to aid comparison.
- In the short-term, exercise-induced energy expenditure and subsequent energy intake do not appear to be tightly regulated in young people; this acute imbalance is similar to the 'loose coupling' of energy described for adults.
- The relationship between energy expenditure and food intake in young people requires further examination in longer-term interventions. A rigorous protocol is necessary to study parameters under free-living conditions.

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