The metabolic and environmental determinants of obesity in childhood: observational and interventional studies

by

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Abstract

The prevalence of obesity in childhood and adolescence is increasing and is often accompanied by poor physical and psychological health. Cardiovascular risk factors such as hypertension and impaired glucose tolerance are prevalent in up to 30 % of obese children whilst psychological impairments such as low self-esteem and depression are also commonly observed. Numerous factors have been implicated in the development of obesity, and include both metabolic and environmental factors. This thesis explored these determinants with particular reference to the role of physical activity, dietary intake and cardiorespiratory fitness. Obese children and adolescents demonstrated very low levels of physical activity, reduced cardiorespiratory fitness and significant psychological impairments.

Many different interventions have been employed to counteract obesity in childhood; however most are limited by high attrition rates. Children and young people are unwilling to give up sedentary behaviours and therefore the development of interactive media games offers a potential strategy to increase physical activity. This thesis identified dance mat exercise as being sufficiently intense to improve cardiorespiratory fitness in obese, sedentary children and young people. Furthermore 12 weeks of dance mat exercise promoted favourable changes in body composition, cardiorespiratory fitness and psychological well-being; all of which point towards an improved quality of life.

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List of abbreviations

ACSM – American College of Sports Medicine
AHR – Actiheart

ALSPAC – Avon Longitudinal Study of Parents and Children
BCH – Birmingham Children's Hospital
BESAA – Body Esteem Scale for Adolescents
BE_Appearance – Body esteem in the appearance domain
BE_Attribution – Body esteem in the attribution domain
BE_Weight – Body esteem in the weight domain
BF – Body fat
BIA – Bioimpedance analysis
BMI – Body mass index
BMI SDS – Body mass index standard deviation score
BPM – Beats per minute
BREQ – Behavioural regulation in exercise questionnaire
CDC – Centre for Disease Control
CDI – Children's Depression Inventory
CHOL – Cholesterol
CHD – Coronary heart disease
CPM – Counts per minute
CRF – Clinical Research Facility
CVD- Cardiovascular disease
DDR – Dance Dance Revolution
DXA – Dual-energy absorptiometry
ECG – Electrocardiogram
EE – Energy expenditure
FM – Fat mass
FFM – Fat free mass
HR – Heart rate
HR_{MAX} – Maximal heart rate
HRQOL – Health related quality of life
HSE – Health Survey for England
HW – Hydrostatic weighing
IC – Indirect calorimetry
ID – Identification
IGT – Impaired glucose tolerance
IPAQ – International Physical Activity Questionnaire
IOTF – International Obesity Task Force
IMD – Index of multiple deprivation
Kcal - Kilocalories
MEND – Mind, Exercise, Nutrition……Do it!
MET score – Metabolic score
MVPA – Moderate to vigorous physical activity
MS – Metabolic syndrome
NA - Negative affect
NCEP – National Cholesterol Education Project
NHANES – National Health and Nutrition Examination Surveys
NICE – National Institute of Clinical Excellence
NO – Nitric Oxide
PA – Physical Activity
PA - Positive affect

PAEE – Physical activity energy expenditure
PAI – Physical activity intensity
PAQ – A – Physical activity questionnaire for adolescents
RCT – Randomised Controlled Trial
REE – Resting energy expenditure
RER- Respiratory exchange ratio
RHR – Resting heart rate
RMR – Resting metabolic rate
RPE – Rating of perceived exertion
SA – South Asian
SES – Socioeconomic status
SFA – Saturated fatty acids
SHR- Sleeping heart rate
SHOT – Sheffield Obesity Trial
SPA – Social physique anxiety
TEE – Total energy expenditure
TG – Triglycerides
VO_2 - Ventilation
VO_{2MAX} – Maximal oxygen uptake
VO_{2PEAK} – Peak oxygen uptake
VCO_2 – Carbon dioxide uptake
YBRS – Youth Behaviour Risk Survey
WC – Waist circumference
WHO – World Health Organisation

1 CHAPTER 1. GENERAL INTRODUCTION

1.1 Obesity

Over the last 30 years, there has been a worldwide increase in the prevalence of overweight and obesity, with obesity now the most common nutritional disorder in most of the westernised world. Obesity is defined as excess fat accumulation to such an extent that health becomes endangered with numerous methods of classification available. Body mass index (BMI) a simple measure of weight for height calculated as weight in kilograms divided by height in metres squared (kg/m^2) is most commonly used to define obesity at a population level. The World Health Organisation (WHO) has identified classifications of BMI related to degrees of underweight, and overweight or excess weight with critical cut off points identified as $25kg/m^2$ for overweight and $30kg/m^2$ for obesity (1). These cut off points identify the degrees of excess weight that are associated with increased risk of some diseases and have been directly associated with health and mortality in many populations. Using these BMI definitions the prevalence of obesity has dramatically increased over the past 20-30 years. Currently in the USA, over 2/3rds of adults are considered to be overweight or obese (2). The same trend is mirrored in the UK where average adult BMI values stand at $27.2kg.m^2$ for men and $26.8kg/m^2$ for women (3), with 24% of the adult population having a BMI>$30kg/m^2$. Prevalence has more than doubled in the past twenty years and extrapolations based upon recent trends predict that by 2050 the UK could be a mainly obese society (4) (see figure 1.1).

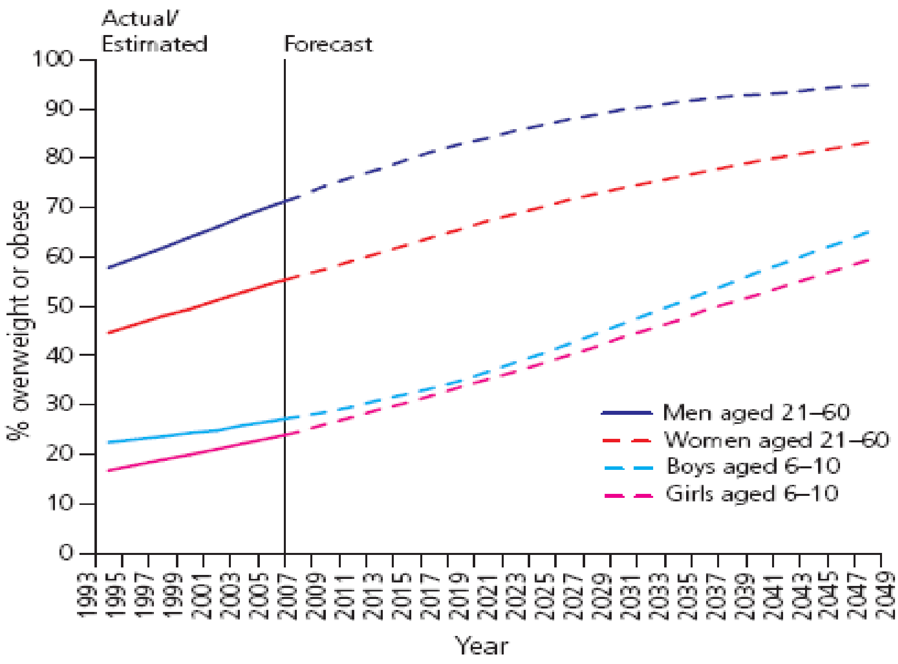

Figure 1-1. Predicted trends of obesity prevalence to 2050 in the UK.

Source: Foresight Tackling Obesities: Future choices – modelling future trends in obesity and their impact on health. (4)

The presence of overweight and obesity contributes to significant health impairments with increases in the risk of cardiovascular disease (CVD), type 2 diabetes and cancer (5;6) as well as significant psychological impairments. Prospective cohort studies have demonstrated increases in the risk of coronary heart disease (CHD) with an 8% increase for each unit increase of BMI (7). Abdominal obesity as indicated by a raised waist circumference or waist: hip ratio presents a further increase for the risk of CHD. The cluster of abnormalities linking obesity, insulin resistance, and CVD risk factors has been termed the 'metabolic syndrome' and is characterised by unfavourable lipid profiles, abdominal obesity and hypertension (8). The presence of the metabolic syndrome increases the risk of type 2 diabetes development. The National Audit Office recently suggested that one million fewer obese people in England would lead to 34,000 less people with type 2 diabetes. The chronic disease burden associated with obesity carries not only significant health implications but also financial repercussions. Current predictions place the cost of obesity to the NHS at £17.4 billion per annum, however if the predictions made by the Foresight report happen, by 2050 the total cost of obesity, could be in the region of £49.9 billion per annum (4).

1.1.1 Obesity in childhood

In children and adolescents, the relationship between BMI and overweight or obesity is affected by variations in age, gender and height. Therefore age and gender percentile charts have been developed with specific reference points for increased BMI (9). These charts allow children to be plotted against normative values. In the UK the British 1990 reference curves developed by the Child Growth foundation are used to identify children who have a BMI >85th percentile as overweight and children with a BMI >95th percentile as obese (9). These growth charts can also be used to calculate a BMI standard deviation score (BMI SDS) or Z score representing increases or decreases around the 50th centile or mean value. Further measures of obesity and related comorbidities in children and adolescents include the use of waist circumference, and body fat %. Waist circumference is indicative of abdominal adiposity, a risk factor for the metabolic syndrome and may be useful to identify children at additional risk. Gender specific waist centile curves have been developed in UK children aged 5-16 years old (10), although there is lack of international consensus for defining central obesity in children. Although BMI is a simple, indirect measure of adiposity it is limited by an inability to distinguish between increased mass in the form of fat, lean tissue and bone and as a result may lead to some misclassification particularly in athletic individuals with a large muscle mass (11). Therefore use of an indirect measure of adiposity should increase the accuracy of obesity classification. Techniques for direct measurement or estimation of adiposity include hydrostatic weighing (HW), dual energy X-ray absorptiometry (DXA) and bioimpedance analysis (BIA) all of which have been validated in paediatric populations (12). Adiposity can be expressed in terms of % body fat, or as total amounts of fat mass (FM) or fat free mass (FFM). At present age and gender appropriate centile curves for body fat % are being developed and therefore this measure should only be used to measure changes over time rather than as a diagnostic tool. On a population level, the linear relationship between percent body fat and BMI SDS suggests that BMI SDS be used as the most accurate surrogate measure of changes in body composition over a period of time (13).

Using the criteria discussed above, the prevalence of obesity in childhood and adolescence has been shown to be following a similar pattern to that of adults, with dramatic increases witnessed over the last few decades (14). The most recent Health Survey for England suggests that around 30% of UK 2-17 year olds are either overweight or obese, three times greater than the rates observed in 1974 (14-16). The National Child Measurement Programme measures the height and weight of every child in reception and year 6 in England. This allows for actual monitoring of prevalence of raised BMI in this population. In 2009 for the reception year, the prevalence of overweight and obesity was 13.2% and 9.6% respectively. In year 6, whilst the prevalence of overweight was similar at 14.3%, the prevalence of obesity was twice as high at 18.3% (17). This represents a dramatic increase in the prevalence of obesity with age. The prevalence of obesity in UK children is similar to that of the USA where 19% of 6-11 year olds and 17.4% of 12-19year olds are obese (2). Health Survey for England data from recent years would indicate a ‘levelling off’ of obesity prevalence rates in children, especially in girls however more years of data are required to see if this change is sustained or is merely a ‘idiosyncratic anomaly’ (3).

Obesity in childhood and adolescence is associated with the same consequences as for adults with co morbidities such as type 2 diabetes, early markers of CVD and psychological impairment obvious at an increasingly young age (18;19). In addition, obesity in childhood is strongly associated with obesity in adulthood such that 60-80% of obese children become obese adults (20). If comorbidities are present in childhood, and obesity persists into adulthood then disease duration and hence prognosis is worsened.

As already discussed obesity is defined as an accumulation of excess fat to such an extent that health is impaired, and in simple terms arises as a result of a chronic positive energy balance. If energy intake consistently exceeds energy expenditure there is an accumulation of excess adipose tissue, which builds up over a period of time and leaves a person at risk of overweight and obesity. The magnitude of the energy imbalance does not need to be large for a person to be at risk, for example it has been suggested that a negative energy imbalance of just 100kcal/day would prevent unhealthy weight gain in approximately 90% of the US population (21). An imbalance between energy intake and expenditure could arise as a result of excess calorie intake, reduced physical activity or more likely through a combination of both. There are additional factors which contribute to the development of obesity such as the environment and genetic/inherited factors all of which will be discussed in the following sections.

1.2 The causes of obesity in childhood and adolescence

1.2.2 Diet

Diet has long been implicated as a contributor to the development of obesity with both total dietary intake and diet composition playing a role. However the study of the contribution of diet is complex with calorie intake, eating patterns, and food choices all requiring consideration. In addition the accurate measurement of dietary intake is challenging and generally relies on child and parent proxy reports (22).

In the USA, the National Health and Nutrition Examination Surveys (NHANES) have allowed for dietary patterns to be monitored from 1971 to today. A 24 hour recall protocol is followed, with recent findings suggesting that in all populations aside from adolescent girls total energy intake has not changed much over the last 30 years, from 9726±164kJ/day in 1971 to 10127±155kJ/day in 1994 (23). However the pattern of food consumption has changed dramatically with a doubling in the percentage of foods consumed outside of the home (24) and 75% of adolescents reporting consumption of at least one fast food meal in the past week (25). The UK has experienced similar shifts in eating patterns with more emphasis placed on foods consumed outside of the home, sugar sweetened beverages and snack foods. Dietary intake can be assessed in various ways using methods such as the 24 hour recall, or the 3 day food diary; however all are liable to bias. Studies assessing both energy intake and expenditure have highlighted a degree of under-reporting preventing accurate measurement of energy balance. Under-reporting appears to be more common amongst the overweight and obese population and also in children (26). For example 6 year old obese children reported energy intakes that were 86% that of energy expenditure, compared to 98% of energy expenditure in lean children. Although individual discrepancies cannot be solely attributed to mis-reporting dietary intake, similar findings have been previously reported with the level of under-reporting linked to higher BMI and greater unhealthy eating behaviours (27;28).

Despite these limitations, relationships have been observed between dietary intake and measures of obesity; however findings are inconsistent. A longitudinal study of adolescent weight gain found increasing calorie intake to be related to increasing BMI, with an additional 100kcal/day leading to a BMI increase in the magnitude of 0.0061kg/m^2 in girls and

$0.0082 kg/m^2$ in boys over a period of one year (29). Changing patterns of food consumption may contribute to obesity development through increasing energy intake; male and female adolescents who reported eating at a fast food outlet within the last week had reported energy intakes 40% and 37% respectively, higher than those who had not (25). Likewise, factors such as snacking behaviour, eating breakfast and sugar sweetened beverage consumption have also been implicated. Snacking behaviour is known to increase total energy, fat and sugar intake, and has become more prevalent alongside the increasing prevalence of obesity. However no cross sectional studies have shown any direct association and a greater level of proof such as a RCT or case/control cohort study is needed before causality can be inferred (30).

Whilst the exact contribution of diet and excess food intake to the development of obesity remains unclear, it can be said that very small imbalances in energy balance over a prolonged period of time can lead to obesity. For example, a longitudinal study of children and adolescents found that the children who became overweight had a positive energy gap of just 46-72kcal/day compared to those who remained normal weight. This corresponds to an excess food intake of just 100-140kcal/day, equivalent to one digestive biscuit or a banana (31).

1.2.3 Sedentary behaviours

The term sedentary behaviours refers to activities that do not increase energy expenditure above rest but in the literature is often confused with low levels of physical activity. Sedentary behaviour is not just the converse of physical activity as it is possible for children to have high levels of both. Sedentary behaviours are activities which do not require much input from the skeletal muscles involved in the control of movement and posture, the most common example being sitting. The umbrella term also encompasses activities such as television viewing and media use for example personal computers or video games which require minimal exertion from the participant. Increasingly sedentary behaviours are being linked to the development of obesity, with theories being that sedentary behaviours may ‘displace’ participation in physical activity or encourage excess food intake through increased exposure to food advertisement.

Whilst it is clear much of the western world is in the midst of a media revolution, relationships between sedentary behaviours or media use and obesity are inconsistent. The majority of studies use questionnaires to assess screen time or television watching as proxy measures for inactivity and sedentary behaviours. The Youth Risk Behaviour survey (YRBS) in the US, found 24.7% of youths reported watching >4 hours television per day, with significant graded responses for BMI across levels of TV viewing in both sexes (32). In boys, there was a 20-40% increased risk of overweight if they watched >4 hour TV per day regardless of participation in moderate and vigorous physical activity, with this relationship strengthened in females. As a result the American Academy of Paediatrics have suggested that TV viewing in childhood be limited to 2 hours per day (33).

A more recent addition to the YRBS found approximately 30% of US children exceeded the recommendations of <2hours TV viewing per night (34). However observed associations between BMI and sedentary behaviours were weak, and in general they found that meeting physical activity guidelines was more important for obesity control than sedentary time. This may be explained by the younger age of the children who were on average 9 years old. There is evidence to suggest participation in regular physical activity decreases with age, alongside increasing time spent in sedentary behaviour so it may be that 9 years is too young for these associations to be apparent (34). In adolescent females, BMI and body fat % were found to be strongly associated with sedentary time, an association that withstood correction for physical activity (35). This finding contradicts the previous theory of sedentary behaviours mediating their affect through displacing physical activity; however participants were adolescent females who are known to have low levels of physical activity. Studies have also shown a link between childhood TV viewing and adult BMI thought to be either due to a continuity of lifestyle factors or sedentary behaviours in youth helping to determine a pattern of body weight and fitness which remains into adulthood (36).

As well as displacing physical activity, sedentary behaviours are thought to promote obesity through increased snacking behaviour and exposure to food marketing leading to an increased energy intake (37). In the US, TV adverts account for about 75% of food manufacturers marketing expenditure and about 95% of the marketing budget for fast food restaurants (38). Children enrolled on the Planet Health Intervention were followed for a period of time with baseline TV viewing, change in TV viewing and total energy intake all related to BMI. Baseline TV viewing time and change in TV viewing both predicted a change in total daily energy intake, with each hour of TV viewing associated with a 167kcal increment in calorie intake providing support for this (37). However until recently sedentary behaviours have been measured using subjective, self-report proxy techniques and are therefore liable to recall bias. A recent longitudinal study in the UK, the Avon Longitudinal Study of Parents and Children (ALSPAC) used accelerometry to distinguish between sedentary behaviours and low intensity physical activity (39). Boys participated in more physical activity whilst girls spent more time in sedentary pursuits during the week. The minimally adjusted odds ratio of being overweight was 1.18 for every hour spent sedentary in the 12 year old children. When the models were adjusted for moderate to vigorous physical activity (MVPA), these positive associations disappeared, suggesting the effect of sedentary behaviours to be mediated through displacement of MVPA.

Whilst consistent links are shown between sedentary behaviours and BMI, with relationships apparently stronger in females than males, the exact mechanism by which this link is caused remains unclear (40). Average viewing times of children in both the USA and Europe exceed the recommended limit of 2 hours/day with additional time spent using other forms of sedentary media such as video games (34;41). In addition sedentary pursuits are modifiable behaviours and should therefore be targeted by public health interventions with focus not just on increasing physical activity but reducing sedentary time.

1.2.4 Physical activity

As previously discussed obesity arises as a result of a chronic positive energy balance with energy intake consistently outweighing expenditure. This can arise through an excess food intake, minimal energy expenditure or via a combination of both. Physical activity is defined as “any bodily movement by skeletal muscle that results in energy expenditure” or more simply “any bodily movement that enhances health” and encompasses exercise, participation in sports and lifestyle activities such as walking and gardening (42;43). The role of physical activity in the prevention of disease and premature mortality was first noticed in the 1950’s when it became clear that the incidence of coronary heart disease (CHD) of London bus drivers was much higher than that of the bus conductors (44). The occupational physical activity levels of the bus conductors were higher than for the drivers, indicating a protective effect of physical activity on CHD. Since then numerous studies have examined the protective effect of physical activity on the development of obesity and related complications such as type 2 diabetes and CVD.

There is argument as to the amount of exercise required in order for these benefits to be seen. To prevent unhealthy weight gain, it is estimated that an energy expenditure increase in the region of 1500-200kcal per week is needed (45) and that moderate intensity activity of approximately 45 to 60 minutes per day is required to prevent the transition to overweight or obesity (46). Both of these recommendations exceed the current UK and US government guidelines for physical activity participation of "*All adults should accumulate at least 30 minutes of moderate intensity physical activity on at least 5 days of the week*" (47).

Despite these recommendations participation rates in regular physical activity are low with the Health Survey for England estimating that just 30% of UK adults meet or exceed these guidelines (14). The mechanisms by which physical activity mediates these risk reductions are thought to act indirectly through increases in energy expenditure promoting a negative energy balance, and also by directly impacting the cardiovascular system through increased blood flow delivery and enhanced consumption of glucose and lipids in the blood (48). Increased uptake of glucose and lipids following exercise is achieved by a number of different mechanisms all enhanced in those who exercise regularly. Exercise causes translocation of GLUT-4 glucose transported to the cell membrane for uptake of glucose into the muscle, reducing levels of blood glucose , whilst exercise also induces mitochondrial biogenesis to increase mitochondrial number and density (48).

1.2.4.1 Children and adolescents

1.2.4.1.1 The measurement of physical activity

Physical activity patterns of children are sporadic, intermittent and spontaneous in nature, and thus more difficult to measure accurately. The accuracy of subjective measures of physical activity is affected by the ability of the participant to recall specific behaviours, and in children may also be affected by the perception of the parent. The gold standard for measurement of energy expenditure is doubly labelled water (DLW). This technique involves the person consuming a bolus of stable isotope labelled water, the expiration of which is measured in urine samples. The elimination rates of O-18 and deuterium are measured over time through regular sampling of heavy isotope concentrations in urine. Some of the administered O-18 equilibrates in the body with the body's bicarbonate and is dissolved in the CO_2 pool. The deuterium change in urine over time can be used to compensate for the loss of O-18 in water loss and therefore the remaining net loss of O-18 is in CO_2 production. This allows for an estimation of total metabolic rate. Whilst DLW is the most accurate measure of total energy expenditure which can be used to estimate physical activity energy expenditure (PAEE) under free living conditions; the type, duration and intensity of the activity cannot be determined (49). Objective techniques involve the measurement of a physiological parameter such as heart rate or acceleration and include motion sensors and heart rate monitors. These offer access to additional information on the intensity and duration of the activity. Accelerometers quantify one or more dimensions of movement in the body segment to which it is attached, and then express this in terms of movement counts. These arbitrary counts can be translated into an estimate of physical activity intensity and energy expenditure although intensity thresholds vary widely between monitor brands and also within age and gender groups (50). For example the thresholds decided to represent MVPA will vary between types of monitor. Heart rate (HR) monitoring can be used in free-living to assess PAEE however large intraindividual variations in the relationship between HR and PAEE mean that some form of individual calibration of the HR-PAEE relationship is required (51). The development of new combined accelerometry and heart rate monitors may offer enhanced accuracy and ease of assessment of physical activity. A branched equation modelling technique has been developed which combines heart rate and accelerometry to provide a more accurate estimation of physical activity intensity (PAI) and physical activity energy expenditure (PAEE) (52). In past studies heart rate monitoring was found to overestimate PAI whilst accelerometry often underestimated PAI. The combination of the two techniques improves the accuracy and also reduces the need for individual calibration. Regardless of the measurement technique, it is well known that the process of observation alters the phenomenon being observed, termed the 'Hawthorne effect' and therefore at least 4-5 days of measurement is required in children to achieve a reliability score of 0.8 (53).

1.2.4.1.2 Participation rates

Participation rates in regular physical activity have been extensively studied with widely varying results depending upon the method of assessment, and population studied. There is substantial evidence for the health promoting effect of regular physical activity in children and adolescents as summarised in a recent systematic review by Strong and colleagues (54). It was concluded that in order to promote a range of health improvements, all children should participate in at least 60 minutes of moderate to vigorous physical activity (MVPA) every day. The Health Survey for England (HSE) uses a combination of objective and subjective measures of physical activity to track the physical activity and sports participation levels of children and young people in the UK (14;15). In 2008, 95% of children reported participating in at least some form of activity on the previous 5 days however activity levels were only sufficient in 32% of the boys and 24% of the girls to meet the guideline levels. A significant age related decline was observed especially in girls for whom activity levels declined from 8 years onwards. Objective measurement of physical activity using accelerometry suggested that subjective measures may underestimate MVPA in younger children and over estimate in older children. Accelerometry found average daily time spent in MVPA to be 85 minutes for the boys and 61 minutes for the girls, with 33% of boys and 21% of girls achieving guideline levels. The ALSPAC study is a birth cohort study of mothers and their offspring followed from 1990 onwards (55). Physical activity levels were measured in over 4000 11 and 12 year olds enrolled using the MTI accelerometer worn for 7 consecutive days. A calibration study used indirect calorimetry to identify the accelerometer counts which corresponded to moderately intense physical activity, established in this study as 3600counts/minute (cpm). Overall boys had higher activity levels than girls and more boys reached the recommended activity levels of 60 minutes daily MVPA; 5.1% compared to 0.4% of girls. The median time spent in MVPA was 25 min/day for boys and 16 min/day for girls, much lower than reported in the HSE and in previous European studies (3;56). Although the same accelerometer was used in the European Heart Health study, the threshold level for MVPA counts/min was 1500cpm, much lower than the 3600cpm used by ALSPAC (56). In 9-10 year old children from the North East of England a region where childhood obesity is highly prevalent, 5 days of accelerometry was used to assess the effect of applying different accelerometry thresholds on levels of compliance with MVPA recommendations. Using the recommended physical activity thresholds of >1100cpm (57), 97% of children complied with recommendations however when the stricter threshold of >3600cpm was applied, compliance reduced dramatically to 2% of girls and 7% of boys. It is clear that numbers of children who fulfil guideline levels of MVPA depends upon the threshold level used; however participation rates are consistently low and are decreasing in line with increasing obesity. In addition the age related decline in PA participation is well established as is the tracking of PA from childhood to adulthood (58).

1.2.4.1.3 Physical activity and body composition

The association between objectively measured physical activity and body composition in children and young people has been extensively studied though differing methods of assessment and analysis used have resulted in differing results. In a cross-sectional sample of 4661 12 and 14 year old girls, physical activity measured using 6 days of accelerometry was expressed in terms of moderate to vigorous physical activity (MVPA). Minutes spent in MVPA was related to body composition, with a 1 minute increment in MVPA associated with a 0.05kg/m^2 reduction in BMI following a graded response (59). In the UK, cross sectional analyses of 5,500 children enrolled in the ALSPAC study assessed MVPA using accelerometers for 7 days, relating this to fat mass as measured using DEXA (60). When physical activity was related to body composition, correlation coefficients were highly significant in boys and girls for both total physical activity and MVPA, remaining significant when related to BMI, fat mass, lean mass and trunk fat. Interestingly the relationship between total physical activity and fat mass disappeared when adjusted for MVPA suggesting MVPA to be more important in the prediction of body composition. These associations suggest an increase of 15minutes of MVPA to be associated with a lower odds ratio of obesity of over 50% in boys and nearly 40% in girls. These findings are supported by a case control study in Sweden involving 18 obese adolescents and 18 age and gender matched lean controls (61). Total energy expenditure (TEE) was assessed using doubly labelled water (DLW) and PAEE was predicted as 0.9TEE – resting metabolic rate (RMR). In addition PA was measured using accelerometry for 14 days. Whilst total PA, accumulated time and continuous time of MVPA was significantly lower in the obese adolescents, there were no between group differences in PAEE and TEE. This is probably explained by the larger mass of the obese participants resulting in greater energy expenditure for any given activity. Therefore either the energy intake of the obese participants is significantly higher than for lean or that time spent in MVPA is more important for the development of obesity. In a cross-sectional study of rural children, obese children exhibited significantly lower total activity counts per day, participation in MVPA and 5, 10, and 15 minute bouts of MVPA per day (62) over the 7 day monitoring period. When PA was analysed in more detail, splitting MVPA into moderate (MPA) and vigorous (VPA) based upon accelerometry counts, it was shown that participation in VPA predicted body composition whilst MPA had no influence (63).

Cross-sectional studies cannot infer causality, for example it may be that reduced physical activity causes obesity or it may be that obesity results in reduced physical activity. Longitudinal studies allow for these associations to be followed over a period of time, and can address the issue of whether children who change their level of activity or inactivity experience changes in body composition and adiposity. One such study in the USA, the Growing Up Today study consisted of 6767 girls and 5120 boys aged between 10 and 15 years followed over a period of one year (64). Self-reported height and weight was used to calculate BMI, and children were grouped based upon their weight status. Physical activity was assessed using a questionnaire that asked children to recall the number of hours per week they had participated in various sports and activities outside of gym class. All activities were assigned a MET score and inactivity was also assessed using a questionnaire. Boys spent considerably more time sedentary than girls but also participated in more physical activity. An increase in physical activity was associated with a decreasing relative BMI in the magnitude of -0.06kg/m^2 per hour of activity for girls and -0.22kg/m^2 per hour of activity in overweight boys. Likewise increasing inactivity was associated with increased BMI in girls only, with all effects increased in overweight children. A longitudinal study of younger children (aged 5 years) in the UK followed 307 children over a period of 3 years. Accelerometry for 7 days assessed PA at each of the four annual time points, and PA was expressed in terms of metabolic scores (MET). Body weight, skinfold thickness and waist circumference were used to express changes in body composition and in addition metabolic status was assessed through four variables; insulin resistance, triglycerides, cholesterol/HDL ratio and mean arterial blood pressure. Girls were significantly less active than boys spending less time at the recommended level of ≥3METs. When compared to current Government recommendations only 42% of boys and 11% of girls achieved >60 minutes/day MVPA. The number of minutes spent in activities ≥3METs was not associated with any changes in body mass, or fatness however there were small to moderate inverse partial correlations between the number of minutes in activity and changes in the composite metabolic z score. It may be that children involved were too young for any associations to be seen and as the prevalence of overweight and obesity at baseline were not reported it is difficult to determine how many children changed their weight status. The lack of consistency may also be linked to the method of assessing change in body mass or adiposity. Body mass index (BMI) is most commonly used to monitor changes in body composition however as BMI cannot distinguish between lean and fat mass, if people gain muscle mass through increased physical activity, they may show gains in BMI whereas in fact excess adiposity has reduced (22).

1.2.5 Physical fitness

Physical fitness is defined as a set of attributes that people have or achieve that relates to their ability to perform physical activity and is a multifactorial construct which encompasses body composition, cardiorespiratory fitness and lung function (65). Cardiorespiratory fitness is a powerful predictor of the development of insulin resistance, CVD risk factors and also obesity (66;67). Furthermore in obese adults, fitness has been shown to alleviate the excess risk of mortality with no elevation of mortality apparent in men with high amounts of fat mass and fat free mass if they were also fit (68). Numerous studies have demonstrated impairments in physical fitness in obese children compared to their lean peers; however the level of impairment depends upon how the authors chose to express fitness (69). Cardiorespiratory fitness is usually defined in terms of maximal oxygen uptake (VO_{2MAX}) which represents the maximal amount at which an individual can consume oxygen. VO_{2MAX} is measured in litres of oxygen uptake per minute, and can be expressed either adjusted for body weight, fat mass and fat free mass or in absolute terms. Obese children have higher FM compared to lean children and therefore differences in body composition should be taken into account (70). The exercise intolerance observed in obese and overweight adolescents has been suggested to be related to the increased metabolic demands of carrying the excess load rather than a reflection of any true decrease in fitness (71). Previous research has demonstrated no differences between lean and obese adolescents in terms of VO_{2MAX} when expressed in absolute terms, however adjusting for body weight leads to significant reductions in the obese adolescents (70;71). Regression analyses revealed FFM to be most strongly associated with VO_{2MAX} and therefore fitness should be adjusted for FFM.

In childhood and adolescence a strong and consistent relationship between fitness, body composition and health parameters such as blood pressure and insulin resistance has been demonstrated, with fitness being a stronger predictor of insulin resistance than BMI (66;72). The fitness impairments observed in obesity may be a result of reduced physical activity but also may arise due to the presence of comorbidities and cardiac constraints reducing functional capacity (71). In a sample of obese youth with type 2 diabetes, 17% of boys and 22% of girls met PA participation guidelines however over 90% of the youths had fitness values below the 10^{th} percentile for age and gender (73). Physical fitness may also predict the development of obesity as demonstrated in a longitudinal study of fitness and BMI change over a 2 year period in 11 year old children; those who were classed as ‘unfit’ at baseline were 3.9 times more likely to gain BMI during the follow up (74). However other contributing factors such as dietary intake and physical activity were not controlled for.

1.2.6 Environment

Participation rates in regular physical activity are decreasing for both the adult and child populations and it has been proposed that changing environments which favour inactive forms of leisure and transportation may be contributing factors. Many factors contribute to a persons PA, including environmental correlates such as proximity to green space, real and perceived barriers to exercise such as body consciousness and social/family support (75). Environmental influences are especially important in children and young people as they tend to have less autonomy in their behavioural choices and are more reliant on input from parents/guardians to provide PA opportunities (76). The current environment is often described as ‘obesogenic’ due to the environmental features which promote obesity inducing behaviours (77) for example sedentary jobs, and reliance on inactive modes of transport.

A significant age related decline in adolescent physical activity is evident, occurring at a younger age in females suggesting there to be changing correlates of PA between childhood and adolescence (3). A number of systematic reviews have been undertaken in an attempt to understand the environmental factors associated with PA in youth and how they change with age (76;77). Local environmental factors such as neighbourhood safety, pavements, and the proportion of green space have all been implicated as predictors for adolescent PA however there is little empirical evidence to support this. There is also limited evidence to support an association between lower rates of obesity and the proximity of physical activity and recreational facilities in adolescents (76). Potential determinants at home included socioeconomic status, parental PA, and perceived social support from significant others and family. It is hypothesised that lower socioeconomic status may restrict children in their choices and opportunities for PA however neither systematic review has found evidence of this (76;77). Environment may also influence the risk of obesity through promoting unhealthy dietary behaviour. For example proximity to a fast food restaurant increasing the likelihood of being obese. In children and adolescents, the proximity of their school to fast food restaurants has been linked to a reduced consumption of fruit and vegetables and increased odds of being overweight (odds ratio: 1.06) and obese (odds ratio: 1.07) (78).

1.2.7 Ethnicity

In the 1960's it was noticed that not everyone in the UK had equal health needs. Those with ancestral origins in the Indian Subcontinent appeared to exhibit a higher susceptibility to CVD following migration to urban environments (79). These observations were later confirmed using UK census data which highlighted increased mortality rates, and prevalence rates of type 2 diabetes, stroke and coronary heart disease (CHD) in those of South Asian (Indian, Pakistani and Bangladeshi) origin (80;81). More recently, rates of ischemic heart disease in South Asian (SA) adults were found to be 30-40% higher than for the general population contributing to a 50% increased age standardised mortality rate. However these health disparities are not limited to the UK, with strikingly high prevalence rates of type 2 diabetes now evident in countries of the Indian subcontinent, particularly in the urban areas as indicated in figure 1.2 (82).

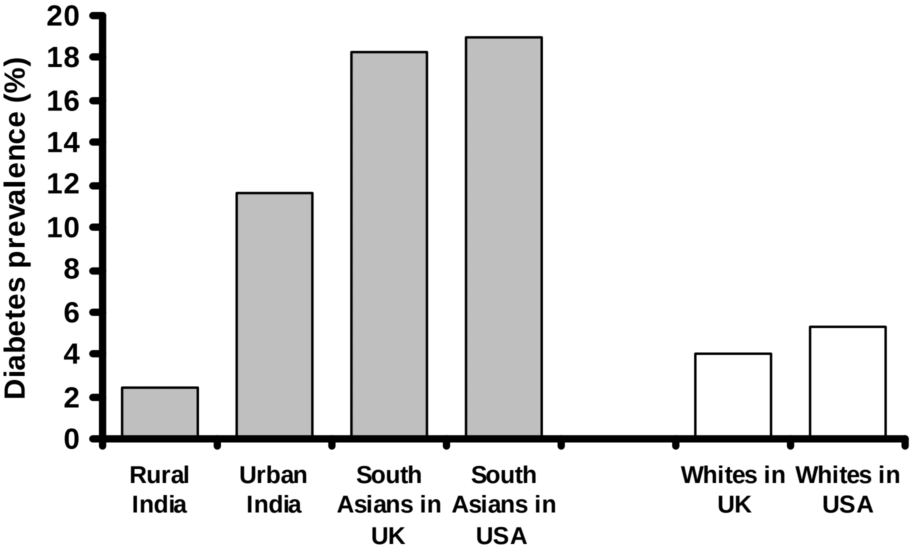

Figure 1.2. Ethnic differences in the prevalence of Type 2 diabetes.

Population estimates suggest that by the year 2010, 60% of the worlds patients with heart disease will be in India (83), and by 2025, India will have the highest concentration of diabetes patients in the world. These ethnic differences are not limited to clinical populations with differences apparent in terms of body composition and associated metabolic abnormalities across all sections of society (84;85). For a given BMI, SA exhibit an increased proportion of body fat and greater amount of subcutaneous fat, an approximate increase of 6% more fat for a given BMI (84). Furthermore biopsies provide evidence for an increased adipoctyte size in SA suggesting the BMI threshold for obesity and related complications to be approximately 2 kg/m^2 lower in SA. This has led to the publication of SA specific BMI points of interest for identification of individuals at an increased risk of diabetes and CVD (86). These BMI points of 23kg/m^2 for overweight and 27.5kg/m^2 for obese have been successfully validated in SA populations however as yet no such points exist for children (87) despite the observed ethnic differences already apparent in children and adolescents. A recent study of 129 healthy 14-17 year olds identified a greater prevalence of overweight and obesity in SA adolescents and a higher level of central adiposity as indicated by the greater waist circumference and greater waist: hip ratio (88). As in the adults, body fat % was increased at all levels of BMI, a finding confirmed in a further study of 1251 children using DEXA to assess body composition (89). In this case, the ethnic differences were noticed to be apparent by the age of 5 years old, and gender differences were also apparent with girls having more body fat than boys for a given age and BMI. Further ethnic differences are apparent in the distribution of fat with SA populations more likely to exhibit raised visceral adiposity than whites (90). Superficial subcutaneous adipose tissue is relatively metabolically inactive whilst visceral adipose tissue is characterised by higher transmembrane fatty acid flux rates and is therefore more closely related to dyslipidemia and increased risk of CVD (90).

The prevalence of individual cardiovascular disease risk factors relating to obesity and their clustering also varies between different ethnicities. The clustering of abnormalities linking obesity, glucose intolerance and cardiovascular disease risk has been termed the Metabolic syndrome and although there are numerous methods of definition, the central components of obesity, glucose intolerance, hypertension and dyslipidemia are consistent. Prevalence rates of the metabolic syndrome differ depending upon the definition used however cross-sectional population studies have shown age standardised prevalence to be highest in SA and lowest in whites (91). The prevalence can vary widely depending upon the inclusion of certain metabolic factors such as waist circumference (WC) and hyperglycaemia (92). For example in young Asian Indian adolescents, applying the NCEP criteria of diagnosis resulted in a prevalence rate of 0.8% which increased to 10.2% when BMI and WC were included as covariates (93). Estimates of the prevalence of the MS in obese SA children has placed it at around 30% (94). In addition the first 8 cases of childhood type 2 diabetes in the UK were all in females of SA or Arabic descent (95). Further childhood cases of type 2 diabetes have since been identified however there remains a greater proportion coming from ethnic minorities resulting in a relative risk of diabetes 3.5 times greater for SA compared to whites (96). The development of type 2 diabetes in childhood is strongly related to the presence of a family history with around 90% of children with diabetes having a positive family history (97). The strong familial element to obesity and related metabolic complications may be grounded in a genetic predisposition of SA to deposit central adiposity but it may also be related to modifiable lifestyle factors such as physical activity and diet (98).

The Health Survey for England 2004 (3) highlighted an ethnic gradient in physical activity participation with the white British population having the highest participation rates and Bangladeshis the lowest. These differences are also apparent in children with participation rates particularly low in Pakistani girls (14;99). The dietary patterns of SA populations are difficult to quantify due to the diverse nature of diets between populations. However a survey of adolescents in the UK found the SA to report high adoption of high fat foods and only 34% reported consumption of fruit or vegetables on the previous day (100).

It is clear that SA populations both in the UK and on the Indian subcontinent experience increased mortality rates, increased prevalence of the MS and type 2 diabetes, as well as an altered body composition. However there are limitations to studying the population as a whole due to the differing lifestyle and behaviour depending upon the geographical location of origin, socioeconomic status and religion. All subgroups of SA do share the same excess

CVD risk and hence the cause is likely to be either genetic in origin or an interaction between genes and the changing environment.

1.2.8 Genetic/inherited factors

The inconsistent relationships demonstrated between environmental factors and obesity and also the fact that not all children are obese has led to the suggestion that genetic or inherited factors may be involved. Previous research has suggested that as the obesity epidemic has exploded in the last 20 years, a period of time not long enough for the human genome to have changed, genes cannot be responsible. However twin studies have demonstrated that heritable factors may be responsible for between 40 and 75% of the inter-individual variation in BMI (101). Heritable factors are likely to operate through a variety of mechanisms for example energy expenditure, energy intake, satiety and body composition. In addition there are various monogenic forms of obesity such as Alstrom syndrome, which account for about 7% of cases of severe obesity in children (BMI>40kg/m^2) (102). Obesity of this severity is present in less than 0.01% of the population and therefore there must be other contributors.

Parental weight and obesity strongly predicts the likelihood of obesity in childhood with an odds ratio of obesity of 2.54 if the father is obese, 4.35 if the mother is obese increasing further to 10.44 if both parents are obese (103). This strong heritability may be related to genes, shared environment or more likely the interaction between the two. Parental weight is related to birth weight which has shown to be a risk factor for childhood and adulthood obesity and mortality for CVD (104). Low birth weight in infancy has been linked to changes in body composition and increased fat deposition in children and adults across a continuum of birthweights with risk of low birth weight further exacerbated by rapid postnatal weight gain (105). The risk is suggested to arise from a ‘Thrifty phenotype’ causing foetal programming in response to undernutrition, however more recently overfeeding in the womb has also been linked to childhood obesity (106). In fact a U shaped relationship is apparent with both small and large for gestational age babies having an increased risk of future obesity and insulin resistance. Heritability could also arise through shared environment as during childhood parents exert a large influence on the behaviour choices of their offspring. Twin studies suggest that a shared environment contributes only about 10% to BMI (107). The ‘thrifty genotype’ and ‘thrifty phenotype’ hypotheses have both been proposed to contribute to the apparent genetic susceptibility of SA populations to obesity, CVD and type 2 diabetes. The thrifty genotype hypotheses suggests there to have been an evolutionary enrichment of thrifty genes involved in the maximising of metabolic efficiency which may have been beneficial during times of famine, though in contemporary conditions where food is in abundance, these genes can predispose individuals to obesity (108). The thrifty phenotype hypothesis on the other hand focuses on the relationship between poor foetal and infant growth and the accompanied increased risk of diabetes development and CVD (109). Evidence against this is mounting with urban Indian babies born with a higher average weight than rural Indian babies yet experiencing a five fold increased risk of diabetes (108).

1.3. The Consequences of obesity in childhood

Obesity in adulthood is associated with significant negative health implications, for example cardiovascular disease (CVD), type 2 diabetes and psychological impairments (7;110;111). In addition, excess body weight increases the risk of mortality from all causes as proven in several large scale longitudinal studies. The US Nurses Health Study found all cause mortality rates to increase significantly with increasing BMI (7) whilst in the Harvard Male Alumni study, a curvilinear relationship was found whereby risk of mortality in men was increased at the lowest and highest values of BMI (112).

1.3.1 Cardiovascular disease risk factors

Obesity in childhood tracks into adulthood with 60-85% of obese children becoming obese adults, and the risk increases with age (20). Furthermore childhood obesity seems to increase the risk of subsequent morbidity regardless of whether it is carried into adulthood (113). Some of this morbidity risk comes from the development of early markers for CVD which occur in childhood. These include hypertension, increased carotid intima media thickness and impaired flow mediated dilatation, all of which have been observed in obese children and young people (114). The Youth Behaviour Risk Survey (YBRS) calculated the odds ratios of elevated blood pressure (EBP) in a sample of 6,364 children aged 8-17 years old. Obese boys were 2.81 times more likely to have EBP than lean, and obese girls 2.55 times more likely (115). Likewise, in a smaller study of 100 children, those who were obese displayed significantly higher blood pressures, and plasma levels of triglycerides (TG), cholesterol (CHOL) and insulin than control subjects (114). Carotid intima thickness and stiffness, both markers of early pre-clinical atherosclerosis, were also significantly increased in the obese children which could reflect structural changes in the arteries indicative of atherosclerosis. These structural changes are in part mediated by the presence of risk factors such as hypertension and insulin resistance (114).

Further risk factors, raised cholesterol and triglycerides, have also been observed in obese children with 58% of the overweight children in the Bogalusa Heart Study found to exhibit at least one risk factor for CVD, with the odds ratio of High density lipoprotein cholesterol (HDL) 3.4 in overweight children compared to lean controls (116). Such early indications of CVD are likely to lead to increasing rates of CVD as the children become adults. A computer simulation model, the CHD policy model, has been used to try and predict the annual excess incidence and prevalence of CHD from 2020-2035 using the prevalence of adolescent overweight in the year 2000. Although this technique is fraught with uncertainty and error, extrapolation data suggests that by 2035 the prevalence of CHD will increase by a range of 5-16% with more than 100,000 CHD cases attributable to the increased obesity (117).

1.3. 2 Type 2 diabetes and the Metabolic syndrome

Insulin resistance is implicated in the development of CVD but is also a risk factor and stage in the development of type 2 diabetes. Until recently, type 2 diabetes was associated with older age, and could largely be controlled by diet and lifestyle; however the childhood obesity epidemic is being associated with an increasing frequency of type 2 diabetes in children. Type 2 diabetes in children was first noticed in 1979 in Pima Indians, an ethnic minority group who exhibit high levels of obesity and diabetes (118). Further studies have reported more cases of childhood type 2 diabetes, predominantly associated with obesity and insulin resistance in ethnic minority populations with a family history of type 2 diabetes (119). Within the UK, the first report of childhood type 2 diabetes identified 8 children, all of whom were female and all of South Asian or Middle Eastern descent (95). On average the children were 13 years old, were 156% of their ideal weight for height, and all had strong positive family history. Type 2 diabetes was then diagnosed in four obese, white adolescents (120) and has since become increasingly diagnosed in children and young people accounting for up to 45% of newly diagnosed cases of diabetes in children in some parts of the USA. A recent survey in the UK identified 77 cases of childhood type 2 diabetes, an incidence rate of 0.6/100 000 per year (121), with the asymptomatic nature of type 2 diabetes meaning there are likely to be more undiagnosed cases in children. Type 2 diabetes is a chronic progressive metabolic disorder characterised by an impaired tissue or organ response to insulin (122), and in progressive stages of the disease by in impaired or delayed insulin secretory response. Pancreatic beta cells in early stages of the disease have a normal capacity to produce insulin however muscle, adipose tissue and liver cells become less responsive to its action. In the early stages insulin levels and insulin secretion are increased to compensate for the observed insulin resistance however following progression towards type 2 diabetes, insulin secretion becomes impaired (122). The primary initiating events in the development of insulin resistance are thought to be endothelial impairments at the level of the microvasculature. Endothelial dysfunction is a component of insulin resistance and results in inadequate vasodilatation and/or vasoconstriction in coronary and peripheral arteries in response to stimuli that cause the release of Nitric Oxide (NO) (123). The deficiency of endothelial derived NO is believed to be the primary defect that links insulin resistance and endothelial dysfunction and is thought to be caused by a cellular disturbance in glucose and lipid metabolism. The cellular disturbance causes production of high levels of reactive oxygen species and reactive nitrogen species which decrease the synthesis and release of NO. These impairments influence the delivery of insulin and glucose to the tissues and hence can cause hyperglycaemia (124). Initial defects in endothelial function and the resulting hyperglycaemia cause an impaired glucose tolerance (IGT), a pre-diabetic state strongly associated with the development of overt diabetes. IGT has been reported to be prevalent in between 21-25% of obese 4 to 18 year olds in the US (125), and 11% of obese UK children (18), contributing to the metabolic syndrome. Just as overweight and obesity have been shown to track into adulthood, the clustering of metabolic risk variables has also been shown to persist over time (126). The Bogalusa Heart study, a longitudinal epidemiological study of the early history of CVD has allowed for the clustering of MS variables from childhood to adulthood to be examined. Over an 8 year follow up, a significant tracking of multiple risk factors (>3 risk factors) was seen, which interestingly demonstrated a stronger correlation than the tracking of individual risk factors

(127). The strength of the tracking increased with age and with ponderal index (weight/height^3) suggesting obesity to be of critical importance in both the development of the MS but also in how these variables change over time and interact with one another (126;127).

1.3.4 Psychological impairments

The physical health consequences of obesity are well documented though there is also growing evidence for a negative impact on psychological well being and quality of life (128). Health related quality of life (HRQOL) is described by the World Health Organisation as an "*individual's quality of life associated with their physical, mental and social well-being*" (129), and reflects how an individual perceives their own well being and function (130). Considerable impairments in health related quality of life have been confirmed recently in a sample of obese children aged 8-18 years, with poor quality of life evident in all domains of functioning implying the day to day life of the youths involved to be severely impacted by obesity (130). Interestingly, parent proxy values of HRQOL were lower than the self report values for most of the scales, a finding which has been confirmed in other studies (128); suggesting parents to perceive more extreme levels of negative HRQOL relative to their offspring. Two further independent studies have found that obese youths currently seeking treatment had a HRQOL similar to youths with cancer, and obesity has also been found to lower HRQOL below levels reported in participants with cardiac conditions, diabetes and gastrointestinal conditions (131). There is also evidence that HRQOL reduces further with increasing BMI, in particular children with extreme obesity (BMI>40kg/m^2) may suffer the poorest HRQOL relative to both healthy and diseased youths (130;132). Factors which may contribute to this impairment in HRQOL include self esteem, body satisfaction, presence of depressive symptoms and social support (133). Body dissatisfaction is highly prevalent in obese children, possibly contributing to the high prevalence of low self-esteem in this population (134) and is also often cited as a barrier to many forms of physical activity. More of a concern is the frequency at which depressive symptoms are noticed in obese children and adolescents. It has been suggested that the social stigmatisation associated with obesity, when combined with the low self-esteem and body dissatisfaction may lead to a chronic state of embarrassment, shame and guilt and eventually leading to depression (135). A national survey of adolescents in Australia found 8.8% of the participants displayed depressive mood, with depressive mood at baseline predicting BMI at follow up 1 year later. In a UK based study of 90 obese children and adolescents, 22% of whom were morbidly obese (BMI>40kg/m^2), 30.3% of participants were found to have a score on the Children's Depression Inventory (CDI) indicative of probable depression (136). Furthermore 27% of the participants reported experiencing suicidal ideations. These significant psychological impairments appear to affect everyday functioning with reports of decreased scholastic achievement, increased school absenteeism and lower incomes in adult life (137).

1.4. The prevention and treatment of obesity

1.4.1 Prevention Interventions

It is obvious that the consequences of obesity in childhood and adolescence are serious and can impinge upon physical, psychological and emotional well-being. As discussed, in simple terms obesity arises as a result of a chronic positive energy balance and therefore prevention and treatment interventions should focus on the restoration of energy balance.

1.4.1.1 School based interventions

Persistent obesity is well established by the age of 11 years and therefore many prevention interventions are focused at children below this age (138). It has long been recognised that schools are an effective setting for public health initiatives as they can offer access to a large population of children from a broad range of ethnic and socioeconomic backgrounds, an established infrastructure for the implementation of interventions and also the staff capable of delivering such interventions (139). Children spend approximately half of their waking hours in school during the school year between 6 and 12 years. In addition schools can offer access to facilities for physical activity and dietary change as well as school nurses who can provide a continuum of care.

Generally school based interventions can be categorised into one of three types; educational, environmental or multi-component whole school approaches. Educational interventions focus on changing the knowledge and attitudes of the children and are usually based within the classroom. In contrast environmental approaches act via changing the physical environment, policies or practices within the school to provide more opportunities for children to participate in healthy behaviours. Multi-component strategies combine a number of different components including education and environment as well as involving the families and communities.

Planet Health in the USA in an example of an educational intervention aimed to reduce the prevalence of obesity by focusing on four main behavioural changes including reducing television viewing, increasing MVPA, decreasing consumption of high fat foods and increasing consumption of fruits and vegetables (140). Planet health took the form of an interdisciplinary curriculum intervention with material infused into the core subject areas of physical education (PE), maths, science and social studies. Schools were randomly allocated to intervention or control, with intervention schools then exposed to the 2 year intervention delivered by teachers from within the school who received training from project staff. Primary outcomes include obesity assessed by BMI and skinfold thickness, whilst secondary outcome measures included television viewing, physical activity, and dietary intake. At baseline the prevalence of obesity was 28% in control and 27% in intervention schools, with African American students more likely to be obese. After controlling for baseline covariates, following 2 years of intervention the prevalence of obesity amongst female students was significantly reduced however there were no significant differences in boys between intervention and control. Although there was evidence for a reduction in television viewing time and an increase in fruit and vegetable consumption, no other variables were shown to change and only television viewing time appeared to mediate the intervention effect. A cost benefit analysis estimated the cost per student to be approximately $14 per student with an estimated 1.9% of female students prevented from becoming obese adults (141). The feasibility of adapting this American curriculum intervention for use within UK schools was assessed in a randomised controlled trial (138). A pilot cluster randomised controlled trial was carried out in 19 primary schools, randomly assigned to either a 16 lesson, 5 month intervention or control. The 16 lessons were adapted for the UK curriculum and were taught by teachers who had received training from members of the research team. Questionnaires were completed which assessed time spent doing screen based activities, active travel, and obesity. Non significant reductions in screen time were observed following the intervention. In addition intervention children were more likely to walk or cycle to school despite adjustment for baseline covariates. However there were no differences in mean body mass index or the odds of being obese between intervention and control. In conclusion it would appear that multi faceted school based interventions can be a cost effective means of reducing screen time in young children; however effects on obesity prevalence are minimal.

A more successful school based intervention in the US achieved a 50% reduction in the incidence of overweight in intervention compared to control schools over a 2 year period (142). The multi component School Nutrition Policy initiative was implemented which included nutrition education, social marketing and parent outreach. Central to the intervention was the nutrition policy which resulted in the change of all foods sold and served at intervention schools to meet the Dietary Guidelines for Americans. Although focus was on nutritional education; physical activity and sedentary behaviours were included as outcome measures alongside the prevalence of obesity. In 600 control and 749 intervention pupils aged 11 and 12 years old, significantly fewer children in the intervention schools became overweight after 2 years (7.5% compared to 14.9%), an odds of obesity incidence 33% lower for the intervention group. In addition in the intervention group the prevalence of obesity had decreased by 10.3% whilst increasing by 25.9% in control schools. Self-reported consumption of energy, fat, fruits and vegetables were similar for intervention and control and decreased in all schools. Physical activity decreased in both intervention and control schools, however the time spent inactive also decreased following 2 years of intervention suggesting sedentary behaviours to be important in the development and treatment of obesity. Further primary school and nursery based interventions in the UK which focused on increasing physical activity had no significant effects on obesity or physical activity behaviours suggesting multi faceted approaches to be more successful (143;144). In conclusion, school would appear to be an appropriate place to perform public health interventions due to the established infrastructure and easy access to a large population, however so far interventions have only been successful in girls and improvements seen are mainly marginal changes in diet or sedentary behaviours.

1.4.2 Treatment Interventions

1.4.2.1 Clinical populations

Whilst community and school based interventions often focus on the prevention of obesity, the current obesity epidemic means there is a need for interventions which focus on treating the already obese or those at high risk of obesity development. Often children with obesity and related comorbidities are receiving clinical care however there is a lack of resources and appropriate personnel within many clinical settings. Therefore whilst the clinical needs of the children are assessed, there is little emphasis on behaviour change, quality of life and well being. In adults, successful weight management interventions have included the use of calorie restricted diets, structured and lifestyle physical activity, pharmacological agents such as sibutramine (145) and bariatric surgery (146) many of which have been replicated in the paediatric population. However children and adolescents have different requirements to adults and there is therefore a need for tailored interventions which can focus upon sustained behavioural change to hopefully reduce the risk of childhood obesity tracking into adulthood.

1.4.2.1.1 Diet

Dietary interventions alone are traditionally ineffective in the long term with previous studies in adults suggesting 90-95% of individuals who lose weight through calorie restriction to subsequently regain it (147). Therefore effective weight loss is more likely to arise through physical activity or multi-component interventions which combine nutrition, behaviour and physical activity.

1.4.2.1.2 Exercise

Exercise alone is associated with weight loss through increasing energy expenditure and promoting fat oxidation however there are additional significant health benefits which occur as a result of exercise, independent of changes in body weight. These include improved insulin sensitivity, reduced abdominal adiposity and improved psychological health (148). Therefore when instigating an exercise intervention, it is vital that sufficient outcome measures are included which involve not just measures of obesity but also measures of body composition and cardiovascular health. In many studies evaluating exercise interventions, dietary modifications have been included and therefore the independent effects of exercise have not been isolated. For example, one study aimed to evaluate a standardised training programme combined with dietary restriction focusing on the maintenance of fat free mass during weight reduction (149). 30 obese participants completed a 12 week programme, with children assigned to either dietary restriction or dietary restriction plus an individualised resistance training programme. Whilst both groups reduced BMI SDS, fat free mass was maintained in the resistance training group suggesting a beneficial addition of exercise.

Few studies have utilised exercise as a sole intervention tool, one example being the Sheffield Obesity Trial (SHOT). The SHOT trial was a pragmatic randomised controlled trial for obese 11-16 year old children who were randomised to receive either usual care, exercise therapy, or an attention control intervention. The exercise therapy involved an initial 8 weeks of 3 times a week individualised intermittent exercise training with a trained exercise professional followed by 6 weeks of home based exercise. The trans-theoretical model was used as a framework guideline for exercise counselling to promote positive exercise experiences and attitudes. As well as a usual care control group, an attention control group was included in an attempt to control for any attention effects, with this involving a light form of body conditioning exercise. 81 children with a mean age of 13.1 years participated in the study, with significant baseline impairments in self-perceptions observed alongside a high prevalence of depressive symptoms. Adherence to the exercise and attention control sessions was high, however no improvements were seen in BMI SDS following the 28 week intervention. The only changes observed were modest improvements in physical self-worth and self-esteem. The attention control group also exhibited improvements in self-worth suggesting the mediating effect to be the attention and interaction with a fitness-professional rather than the exercise itself. The energy demand of the exercise was low and therefore energy expenditure would have been minimal which may have contributed to the lack of an effect on BMI SDS and other measures of body composition. In order for reductions in weight and adiposity to be seen there needs to be a negative energy balance whereby energy expenditure exceeds energy intake. Circuit training type exercise has been employed in obese children and adolescents with some success (150). A sample of obese children aged 9 years old were recruited alongside lean controls and exposed to 8 weeks of circuit type training 3 times a week. Adherence was high at 90%; however there were no changes in body weight or skinfold thickness at follow up. The same protocol was repeated in adolescents with similar results, although DEXA revealed a significant decrease in body fat in the abdominal and trunk regions, and submaximal heart rates (HR) were shown to reduce indicating a significant improvement in fitness (151). Despite minimal changes in body weight, vascular function dramatically improved following 8 weeks of exercise. Improvements were correlated with increased cardiorespiratory fitness suggesting fitness to be an important management approach to obesity and related comorbidities.

Several reviews have summarised the effects of exercise training on obesity outcomes in children and adolescents concluding that interventions can consistently result in improvements in body composition, physical activity and fitness as well as cardiovascular and metabolic health as indicated by improvements in insulin sensitivity and vascular health (152;153). However there are a limited number of well controlled studies which have followed participants for a prolonged period of time and effects on body weight are inconclusive. A recent systematic review of 14 published studies concluded that an aerobic exercise prescription of 155-180minutes/week at moderate to high intensity is effective for reducing body fat in overweight and obese children, with additional benefit gained from calorie restriction (154).

1.4.2.2Community Interventions

Community and outpatient based multi-disciplinary interventions are becoming increasingly popular for the treatment of childhood obesity with focus on fostering sustained behaviour change in children and their families using group based approaches to provide social support and motivation. One such example is the UK based WATCH IT programme developed in association with the NHS local health authority in Leeds. The programme was developed to address the needs of obese children from disadvantaged communities and involves three main components; group activity sessions, group parenting sessions and frequent individual appointments. Families commit to attend for 3 months but are offered to renew 3 monthly for one year. All clinics include hour long activity sessions conducted by qualified sports coaches with the focus on participation and fun rather than competition. The pilot study of 94 children with an average baseline BMI SDS of 3.09 revealed significant baseline impairment of quality of life and self-image. By 3 months, 54% of children had shown a decrease in BMI SDS increasing to 71% of children at 6 months. A similar idea was developed from Great Ormond

Street, the MEND programme (Mind, Exercise, Nutrition……Do it!) which takes a multi-component approach to childhood obesity offering a twice weekly 10 week programme for children and their families (155). All sessions include one hour of physical activity and a one hour interactive workshop for the children and their parents and sessions are divided by age into mini MEND (aged 2-4years), MEND 5-7s (5-7year olds) and MEND (7-13 year olds). The randomised controlled pilot trial of 71 children enrolled in the MEND project revealed significant reductions in BMI Z score, waist circumference and increased self-report physical activity. Longitudinal follow up in 43 (61%) of the original sample indicated that the observed positive benefits at 6 months were sustained at 12 months suggesting the MEND programme to be an effective and feasible community based treatment intervention. However there may be some retention bias in that the 61% of participants who attended 12month follow ups were more likely to have sustained improvements in body composition. Similar projects exist in both Germany with the 'Obeldicks' programme and in the USA with programmes such as Bright Bodies (156;157). Both programs include nutrition education, exercise and behavioural modification for children and their families and both resulted in significant reductions in overweight, BMI SDS, and body fat % at the end of the intervention with changes shown to be independent of the child's gender, age and BMI. In both cases improvements were sustained, for up to 2 years for Bright Bodies and still evident after 3 years in Obeldicks. Compared to school based and exercise alone interventions, community based multi-component programmes appear to produce the most significant improvements in body composition however they are often poorly evaluated in terms of fitness, body composition and metabolic parameters. In addition, despite the multi-disciplinary approach and access to support, adherence rates are low, with the Bright Bodies program reporting adherence of 60% at 6 months and 53% at 12 months.

1.4.2.3 Novel interventions

As previously discussed the adherence rates of obese children and adolescents to traditional exercise interventions is low with attrition rates of up to 30% at 6 months reported (158). This may be due to the real and perceived barriers to exercise commonly reported for example body consciousness, lack of access to facilities and social stigmatisation (159). Unless exercise interventions address these barriers and provide motivation for the participants, attrition will remain high. Children and young people spend a lot of time engaged in sedentary behaviours such as video games, and a survey in the US revealed that whilst teenagers are aware of the benefits of regular exercise and are willing to do more exercise to gain these benefits, they are not prepared to sacrifice time spent watching television and playing computer and video games (160). In addition, reports suggest that as many as 100% of 6-10 year olds and 97% of 11-15 year olds in the UK play some form of electronic game on a weekly basis (161). As a result, the development of interactive video games may offer a potential solution to increasing physical activity in a previously sedentary population.

Interactive video games act via increases in energy expenditure. The alternative type of interactive gaming termed 'exergaming' encourages active participation and incorporates games such as the Nintendo Wii, Sony Eye Toy and Konami Dance Dance Revolution (DDR). The Nintendo Wii is a home video game console which includes a handheld pointing device and wireless detector, which allows for acceleration to be recorded in 3 dimensions. Games for the Wii include Wii sports, involving boxing, bowling, and golf whereby the player is required to make the appropriate action which is reciprocated on the screen. The energy expenditure of Wii sports has been evaluated and found to be 30kJ/kg/min (162). April 2008 saw the launch of Wii FIT, a game which involves the use of a balance board, and includes 4 types of exercise, aerobic exercise, muscle conditioning, yoga poses and balance games. The Sony Eye toy is a digital camera device worn by the user and used alongside a Playstation which allows for interaction with games using motion, colour detection and sound. When evaluated in a sample of 8-12 year old children, the eye toy was found to increase energy expenditure by 108% over resting values. The interactive dance game concept involves the use of a dance mat connected to either an arcade game or home computer. Dance mats are used alongside games such as dance factory where a song is played and on the screen is displayed a series of ‘moves’. The user is required to touch the appropriate arrow on the mat in the order shown on the screen. The dances vary in terms of difficulty and some allow the user to input their own music.

In the USA the most popular version is the DDR game which is predominantly an arcade game but can be used with a personal computer. Interestingly in China the DDR game is considered a health care product and in Korea, DDR is used within specialist obesity hospitals. A number of studies have been published which aimed to asses the energy expenditure of the DDR game, thereby testing its feasibility as an exercise device. In all cases despite an observed dissociation between heart rate (HR) and VO_2 responses, continuous dance mat exercise was found to be moderately intense suitable for use in exercise interventions (163;163-165).

A pilot study in obese 9-18 year olds provided all participants with a DDR and asked them to perform exercise on 5 days of the week for 30 minutes at a time (166). Adherence was recorded through the use of a diary and a video memory card and biweekly phone calls were conducted to maintain use. Despite these efforts, only 40% of the children performed dance mat exercise at least twice a week at 3 months, reducing to 9% by month 6. Given the low adherence, regression models adjusted for baseline BMI SDS found the use of DDR to not be associated with change in BMI. A larger study involving predominantly lean younger children randomised 60 children to either a 10 week DDR intervention or waiting list control. Children were provided with a DDR game and two dance mats to encourage social play within the home, a written prescription of 120 minutes per week (mpw) of DDR exercise was also provided and follow ups were performed at 10 and 28 weeks. Outcome measures included objectively measured physical activity, sedentary screen time, body composition and adherence to the intervention. Self-report DDR use was 89±82mpw over the first 10 weeks, decreasing to 60±61mpw by week 10. There was a statistically significant increase in vigorous physical activity following the intervention, combined with a reduction in sedentary screen time which remained up to 28 weeks. The majority of the children were lean at baseline and therefore as expected there were no changes in BMI Z score across the intervention. Focus groups with both the participants and their parents identified general satisfaction and enjoyment with the DDR game, with more than half of the parents believing DDR to ultimately increase their child's PA and that they would recommend the game to others. Further pilot studies in children using active games such as the DDR have also reported increases in physical activity, reductions in sedentary behaviours, slight reductions in body weight, and improvements in cardiovascular parameters such as flow mediated dilation (167;168). However studies so far have predominantly involved lean or overweight children who have relatively high levels of physical activity at baseline, therefore involving obese and sedentary children may result in greater improvements.

1.4.2.4 Clinical/inpatient interventions

In some situations the obese child or adolescent has significant medical morbidities and have failed to achieve improvements in community and school based programmes. In these cases, inpatient or camp style interventions are most effective as they remove the child from their usual habitat, thus enabling the environment to be controlled which may help children to overcome the body related and social barriers to behaviour change. Such examples include the US based Wellspring summer camps which have now been introduced in the UK and the Carnegie camps in the UK (169). These residential camps are able to have control over dietary intake, offer behavioural counselling and provide daily physical activity for overweight and obese children for a period of time usually ranging from 1 month to 12 weeks. In the USA, these camps are becoming increasingly popular, however despite impressive success stories there are limited scientific studies published providing empirical evidence for their success. In the UK Carnegie camps have evaluated the short term and sustained outcomes of their residential programme using a convenience sample of local children as a quasi control group (169). Campers spend on average 4 weeks at the camp, losing an average body mass of 6kg and average BMI SDS reduction of 0.28. Increases in fitness were accompanied by reductions in blood pressure and improvements in self-esteem and all improvements were associated with length of stay at the camp. A similar idea is that of inpatient multi component interventions where again dietary intake and physical activity can be largely controlled. A 10 month inpatient program for severely obese individuals succeeded in promoting an average 19% weight loss and 42% reduction in fat mass. Although having control over diet and physical activity appears to bring about significant improvements in body composition and associated health parameters, the cost of these types of interventions are substantial and therefore unsuitable for large numbers.

1.4.2.4.1 Pharmacological intervention

In obese adult populations pharmacological agents are used to treat obesity and related metabolic complications such as insulin resistance and type 2 diabetes. These agents include

Metformin which acts via reducing hepatic glucose output, Orlistat which prevents the absorption of up to 30% of dietary fat and sibutramine which increases satiety and thermogenesis. In children and adolescents however the efficacy of these pharmacological agents is less well established. A randomised double blinded trial of 12 months sibutramine treatment versus behavioural intervention in 12-16 year olds found larger reductions in BMI (-2.9kg/m2) and greater improvements in TG, HDL, and fasting insulin following the sibutramine treatment (170). Despite these observed improvements, sibutramine has now been removed from the market and is no longer available as a treatment option. Metformin has been proven to be successful in obese children and adolescents with 6 months treatment resulting in significant reductions of weight (-4.5kg), BMI (-1.26kg/m^2) and increasing insulin sensitivity (+0.17Mu/litre/min) (171). This study was performed on a very small sample of just 28 participants and therefore there is a need for larger scale studies to assess the clinical efficacy of such agents in children and adolescents something which is being done in the UK as part of the MOCA (Metformin for Children and Adolescents) trial.

1.4.2.4.2 Bariatric surgery

Bariatric surgery is now well established as a treatment option for obese adults who have been unsuccessful in previous attempts to lose weight, and surgical techniques have developed from the traditional Roux en Y bypass approach which involves manufacturing a smaller stomach pouch and causes gastric restriction, to the more recent Laparoscopic adjustable gastric band (LGAB) which is a synthetic band filled with saline allowing a variable degree of gastric restriction. In adults bariatric surgery has resulted in significant and sustained weight losses greater than 15% maintained for over 10 years (172). Again in children and adolescents the efficacy of this treatment option is not as well understood as significantly fewer procedures have been performed in this population. In recent years however national trends have reported a threefold increase in bariatric surgery case volumes for adolescents between 2000 and 2003 (173). The largest retrospective study involving children and adolescents followed 33 children who underwent surgery over a period of 21 years (174). Mean BMI loss at 1 year was 16 kg/m^2 and this was sustained at 14kg/m^2 loss after 10 years. A further randomised trial comparing lifestyle intervention with adjustable gastric banding found 84% of the gastric band group to have lost over 50% of their excess weight compared to just 12% in the lifestyle group (175). The striking effect of bariatric surgery on comorbidities such as type 2 diabetes makes it an attractive treatment option for correctly motivated patients who have failed at previous treatment efforts. Therefore the National Institute for Clinical Excellence (NICE) have published guidelines relating to the use of bariatric surgery in children and young people which suggest it should be considered only in exceptional circumstances and only if the patient has reached or nearly reached physical maturity (176). In addition, patients should only be considered if they have a BMI>40 kg/m^2 or a BMI>35 kg/m^2 plus the presence of at least one co-morbidity that could be improved with weight loss. A commitment to change must be demonstrated by the patient and the provision of a specialist after care programme including input from dieticians and the surgical team are also required.

1.4.2.5 Physical activity dose

Previous research has demonstrated a beneficial effect of physical activity and exercise for the prevention and treatment of obesity, with improvements in cardiovascular disease risk factors evident without any change in body weight. However it is yet to be established in the paediatric population the amount of exercise required to promote favourable changes in body composition and metabolic health. Current guidelines recommend all children and adolescents participate in at least 60 minutes of moderate to vigorous physical activity (MVPA) every day (177). However in adults there are additional guidelines for the exercise intensity required to improve and maintain fitness, given as reaching a heart rate 55-90% of maximal and a VO_2, 40-85% of $VO_{2RESERVE}$ (VO_{2MAX}-VO_{2REST}) (177). No such guidelines exist in children although a recent review has suggested that for training to induce significant improvements in aerobic fitness, the intensity should be higher than 80% maximal heart rate (178). For adults, an energy expenditure of 1500-2000kcal per week is recommended to promote weight loss and maintenance yet this has not been established in children. The amount of energy expenditure required to promote weight loss will clearly depend upon energy intake as the level of energy imbalance will influence the energy deficit and hence weight loss. It has been suggested that an energy deficit of just 100 kcal/day would be sufficient to prevent obesity in 90% of the US population (21) especially if sustained over a long period of time. There are many additional benefits to regular physical activity that can be observed regardless of changes in body weight for example improvements in glucose tolerance, reduced blood pressure, reduced waist circumference and improved psychological well being. In addition, there is some evidence to suggest that participation in moderate and vigorous activity is more important for the promotion of health and maintenance of weight rather than physical activity energy expenditure. Therefore it is important that the amount, duration, and intensity of activity required for improvements in health and well being are quantified in overweight and obese children and adolescents so that future recommendations can be made.

1.5 Conclusion

In conclusion, obesity is a complex disorder with numerous contributing factors including environmental and genetic factors plus modifiable behaviours such as physical activity and diet. Obesity in childhood and adolescence is associated with significant physical and psychological impairments contributing to an overall reduced quality of life. Significant ethnic differences are apparent in the risk and prevalence of obesity and related metabolic risk factors such as impaired glucose tolerance, and type 2 diabetes with populations of South Asian origin within the UK experiencing significantly increased risk of obesity and CVD mortality. SA children and adolescents also exhibit unfavourable body composition, insulin resistance and lipid profiles compared to the white UK population. There are potential genetic and environmental factors however the contribution of lifestyle factors such as diet and physical activity is not well understood especially in the paediatric population.

In simple terms obesity is associated with a chronic positive energy balance and therefore prevention and treatment interventions focus on the restoration of this imbalance through increasing physical activity and reducing dietary intake. The most successful interventions encompass several disciplines for example promoting physical activity, nutrition education, and educating behaviour change. However regular physical activity can promote improvements in cardiovascular health in the absence of any changes in weight and is also associated with increased self-esteem. In obese children and young people, adherence to traditional exercise interventions is low with attrition rates of up to 60%; however the development of interactive media games may provide a solution and allow for physical activity to be increased in a previously sedentary population. The majority of children and young people spend significant portions of the day engaged in sedentary behaviours such as TV viewing and personal computer use and therefore if these activities can be replaced with active media activities, energy expenditure will be increased and hopefully weight loss will be initiated. It is important that the quantity and duration of the physical activity required to promote favourable changes in body composition is established for children and adolescents. It is also important that physical activity interventions are substantially evaluated using adequate outcome measures for example using additional measures of adiposity to BMI and objective measures of physical activity.

The general aims of the PhD thesis are to explore, using objective measurement techniques, the factors which contribute to obesity in childhood and adolescence. These factors will then be explored in terms of gender and ethnic differences and used to develop interventions which are appealing to the population in question.

2 CHAPTER 2. AIMS AND HYPOTHESES

2.1 Primary aims

Aim 1: To develop a novel exercise intervention using dance mats to encourage physical activity in obese children and young people. The exercise prescription of the intervention will be developed based upon the baseline physical activity levels of the children.

Hypothesis 1: It is hypothesised that in obese children and young people, continuous dance mat exercise will be sufficiently intense to promote improvements in physical fitness. It is hypothesised that the fitness levels of the obese children will be significantly lower than for the lean children and therefore dance mat exercise will be more intense.

Aim 2: To test the efficacy of the dance mat exercise intervention in a sample of obese children and young people.

Hypothesis 2: It is hypothesised that dance mat exercise will be an appealing form of exercise for obese children and young people and therefore adherence will be high. It is also hypothesised that if the children achieve the prescribed amount of exercise, favourable changes in body composition and physical fitness will be observed.

2.2 Secondary aims

Aim 1: To determine if observed ethnic differences in body composition can be explained by differences in lifestyle behaviours for example physical activity and dietary intake.

Hypothesis 1: Prior research using subjective measurement of physical activity has indicated that SA children may participate in less physical activity than their white peers (179). It is hypothesised that obese SA children will participate in less objectively measured physical activity than obese white children. Based upon previous research it is also hypothesised that SA children will consume a higher dietary intake than white children, with more energy coming from fat sources (180).

Aim 2: To examine the changes in psychological well-being observed over the 12 week exercise intervention.

Hypothesis 2: It is hypothesised that obese children enrolled in the exercise intervention will display signs of psychological impairment at baseline. It is also hypothesised that improvements will occur over the 12 week intervention.

Aim 3: To determine if motivation to exercise is related to participation in objectively measured physical activity either at baseline or after the 12 week intervention.

Hypothesis 3: It is hypothesised that intention to exercise may be reflected in participation in regular physical activity. Changes in intention and motivation to exercise will be reflected in changes in physical activity participation.

3 CHAPTER 3. GENERAL METHODS

3.1 Study Design

The intervention study was designed as a prospective observational study. This study design was limited by the lack of a control group such that the treatment effects cannot be established. This design allows for a novel intervention to be trialled in a specific population, with acceptability and faesibility examined as differences from baseline to 12 weeks rather than as treatment versus control. All obese children who attended the clinics were offered the intervention. Those who did not wish to participate were offered the choice of participating in baseline assessments and therefore the characteristics of participants and non participants could be compared and any bias in participant selection can be examined. A non-intervention lean control group was recruited to allow for the baseline characteristics of the obese children to be compared with a non-obese age and gender matched population. The study requirements for the intervention included three visits to the clinical research facility (CRF) at the Birmingham Children’s Hospital at baseline, a 6 week follow up and one further visit at 12 weeks, with a total contact time of approximately 13 hours. Obese and lean participants who only participated in the baseline assessments were required to attend the CRF on only one occasion.

3.2 Recruitment

Participants were recruited from the general paediatric clinic led by Dr Geoff DeBelle and the endocrine clinic led by Professor Barrett at the Birmingham Children’s Hospital. Referral to these clinics was through general practitioners and other multi-disciplinary hospital team members. All overweight or obese patients who attended these clinics were identified by the clinicians and provided information. Criteria for inclusion were age 9-18 years old and

BMI>95^{th} percentile for age and gender. Clinicians had been briefed upon the general study aims and criteria for inclusion and exclusion. Exclusion criteria included refusal of the parent/guardian to provide informed consent, the presence of learning difficulties, and the presence of any medical condition which would prevent exercise (for example severe asthma). As this was an inclusive study, there was no exclusion criteria based around the presence of cardiovascular risk factors, the metabolic syndrome or the prescription of any medicines known to affect insulin sensitivity such as Metformin. All eligible children and their parents or guardians were provided with full study information. This included parent and child information sheets with a full account of the study including background, potential benefits to taking part, and full descriptions of the procedures involved. Approximately one week later, a phone call was made by the principle researcher (Catherine Falconer) to the interested families. This phone call was to invite the children/adolescents and their parents/guardians to ask any questions concerning the study requirements. If the child/adolescent and parent/guardian were interested in participating, they were then invited to attend the Birmingham Children's Hospital (BCH), to undertake informed consent. It was stressed to the families that non participation would not affect the usual pattern of care. Travel expenses to and from the testing site (CRF) were reimbursed and at the end of the intervention participants were able to keep their dance mats and game. Recruitment of the lean, non intervention control group took place through local youth groups and health and fitness centres. A phone call was made to the youth group or health centre and permission asked for the placement of posters and leaflets in a prominent place. Posters included a contact telephone number for the principle researcher and potential participants were invited to contact for more information. Interested children and their parents/guardians were then provided with full study information which included parent and child information sheets. A follow up phone call was made to invite the child/adolescent and/or their parents/guardians to ask any questions concerning the study and then to arrange an appointment at the CRF for completion of informed consent.

3.3 Consent and ethics

All children and adolescents provided informed consent prior to participation. Informed consent was obtained by the principle researcher (CF). All children/adolescents and their parents or guardians were made aware that participation was entirely voluntary and that they were free to withdraw at any time for no reason without affecting their usual standard of care. For children under the age of 16 years old, informed consent was also obtained from a parent and/or legal guardian. The Black Country Research Ethics Committee granted full ethical approval for this project (07/H1202/150). All personal data used within the study was maintained in accordance with the data protection act 1998. Upon recruitment, all participants were given a unique identification (ID) number which was used on all future paper and computer records. There was one document linking the names to the ID numbers which was kept under lock and key in the Wellcome Trust Clinical Research Facility (CRF) at the BCH. All computer records were password protected and made anonymous, whilst paper records were stored in a separate locked filing cabinet in the CRF. Upon study completion, all personal data including paper and computer records will be kept in a locked filing cabinet within the CRF for 5 years.

3. 4 Sample size

No formal power calculations were performed as the initial aims of the study were to establish the feasibility of exercise interventions in this particular sample; and to establish the effect size of the intervention in preparation for a formal larger scale clinical trial. The data gained from this multi-ethnic cohort will be used in sample size calculations to inform further studies and description of this cohort will provide new information on the prevalence of co-morbidities and risk factors. However for examining potential ethnic differences in physical activity, it was estimated that a cohort of 30 children from two ethnic groups (White and South Asian) would be sufficient. This was based on a previous study by Williams et al, who compared background levels of physical activity levels in 334 South Asians and 490 non South Asians, all aged 14-15years (181). It was found that in the general population (non South Asians), 40% of males and 20% of females undertook at least 20 minutes of exercise per day; compared with 26% of males and 16% of females in the South Asians.

3.5 Baseline Measurements

All measurements at baseline and follow up were performed by the principle researcher (CF) to reduce intraindividual variability. All measurements were performed within the Wellcome Clinical Research Facility at the BCH. Baseline measures were taken following informed consent and included the following primary and secondary outcomes (figure 3.1).

Primary Outcomes	**Secondary Outcomes**
Anthropometry and demographics: • Age • Height • Weight • Waist circumference • Index of multiple deprivation • Ethnicity	Resting Energy Expenditure (REE)
Body composition: • Body fat % • Fat mass, (FM) • Fat free mass, (FFM)	Psychological well-being: • Body-esteem • General self-worth • Positive and negative affect • Social physique anxiety • Exercise motivation • Intrinsic motivation
Physical activity: • Physical activity energy expenditure, (PAEE) • Total energy expenditure, (TEE) • Total activity counts • Time spent in moderate-vigorous activity (MVPA)	Dietary intake and sedentary behaviour: • 24hour recall • 3 day food diary • Time spent sedentary
Cardiorespiratory fitness: • McMaster cycle test • $VO2_{Peak}$ • HR_{Peak} • Energy expenditure of dance mat exercise	•

Table 3-1. Primary and secondary outcome measures.

The pattern of recruitment and participation in baseline and follow up assessments is shown below in a flowchart (figure 3.1).

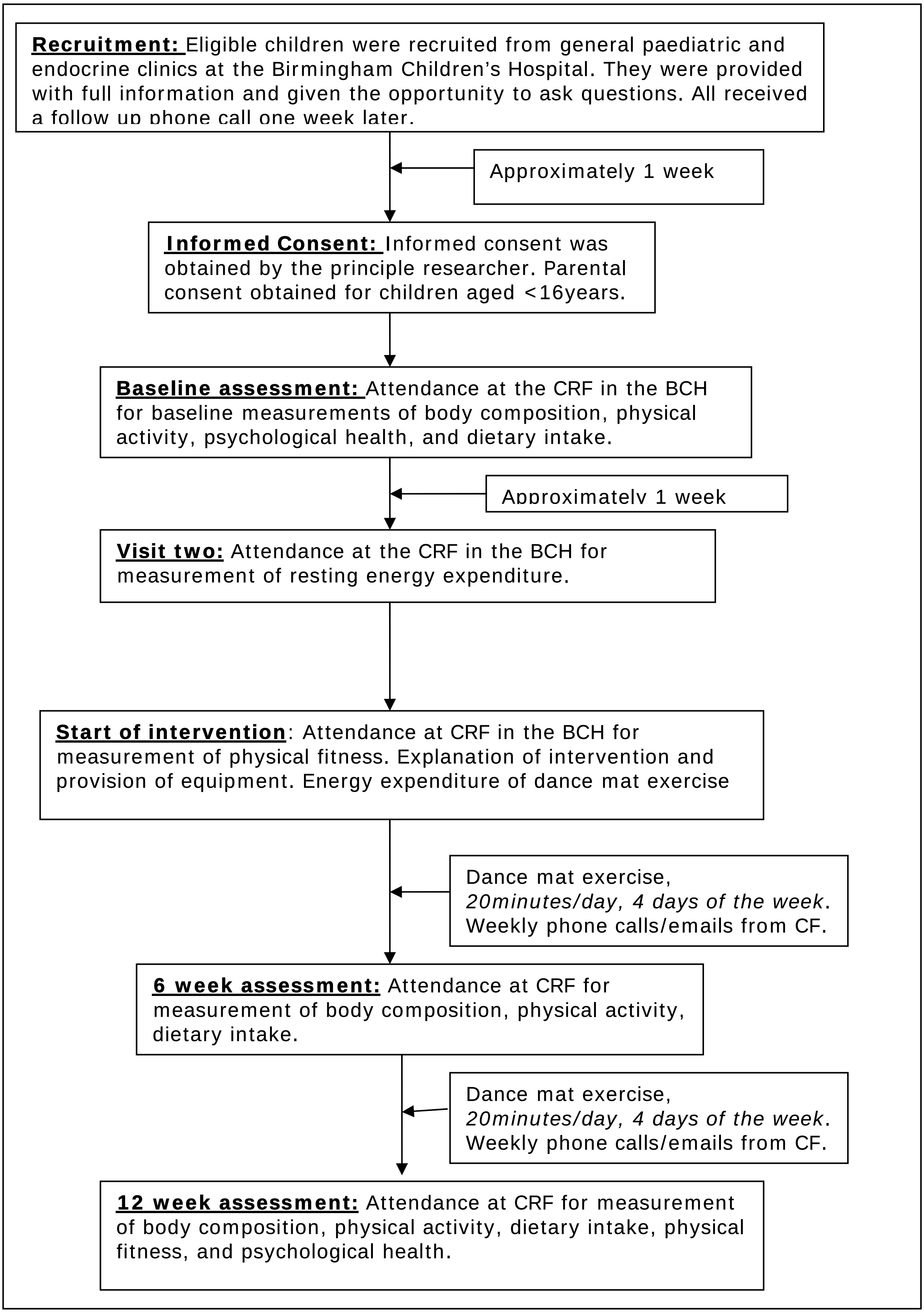

Figure 3-1. A flow chart to represent participant involvement.

3.5.1 Primary outcomes

3.5.1.1 Anthropometry

Body mass was recorded to the nearest 0.1kg with participants weighed in light clothing, without shoes on calibrated scales (SECA, Germany). Height was measured to the nearest 0.1cm with shoes removed using a wallmounted stadiometer (Holtain, UK). Body mass index (BMI) was calculated as weight/(height)^2 according to usual IOTF procedure. BMI was adjusted for age and gender to obtain a BMI standard deviation score (BMI SDS) based on the British 1990 growth reference data provided by the Child Growth Foundation (182). Waist circumference was obtained at the midpoint between the lowest rib and the iliac crest using a non-elastic flexible tape measure. Two measurements were taken and averaged to the nearest millimetre.

3.5.1.2 Demographics

Ethnicity was self-reported by participants and their parents/guardian and checked against hospital records. Current postal address and post code was taken from every participant for their principal address. Post codes were inputted to the Government communities deprivation indices for each lower super output area (www.imd.communities.gov.uk/). The Index of Multiple Deprivation (IMD) was calculated for each post code, which includes domains such as income, education and crime. Indices are expressed as a score and also as a rank percentage comparing the IMD value to the other lower super output areas in the region.

3.5.1.3 Body composition

A Tanita Bioimpedance body fat analyser 410GS (Tanita UK, Middlesex, UK) was used to obtain measures of body fat %, fat free mass (FFM), and fat mass (FM).

Figure 3-2. Tanita Body fat analyser

Bioimpedance works by passing a safe electrical current through the patient's body, and is based on the theory that the electrical conductivity of lean tissue such as muscle and blood is much greater than fat due to the presence of high levels of water and electrolytes. Fat tissue has a lower water content and therefore offers a larger resistance to the electrical signal. The greater the fat mass, therefore the higher the impedance levels. The Tanita 410GS has previously been validated against dual energy x-ray absorptiometry (DEXA) in males and females of varying ages and body mass (183), and was found to be a more precise measure of body fat than skinfold thickness in obese children and adolescents (184). Measurements were performed without shoes and socks and adjustments were made for light clothing. Body fat was recorded to the nearest 0.1%, fat mass to the nearest 0.1kg and fat free mass to the nearest 0.1kg with all measurements performed at least 2 hours fasted.

3.5.1.4 Physical activity

3.5.1.4.1 The Actiheart

Physical activity was objectively measured using the combined heart rate and activity monitor, the Actiheart (AHR).

Figure 3-3. The Actiheart.

Accurate measurement of physical activity is prone to limitations particularly in children for whom activity often takes the form of spontaneous activity as opposed to structured periods of activity. The Actiheart (AHR) is a single piece combined HR and movement monitor worn across the chest, capable of measuring acceleration, HR, HR variability and ECG amplitude for a given time resolution of either 15 seconds, 30 seconds or 1 minute for up to 11 days. The validity and reliability of the AHR as a measure of EE has been proven in healthy adults during treadmill walking and running (185), in adults during lifestyle activities (186), and in children during treadmill walking and running (187). The AHR works on the principle of a branched equation model which alters the contribution of HR and activity models to the calculation of EE, depending upon the type of activity performed.

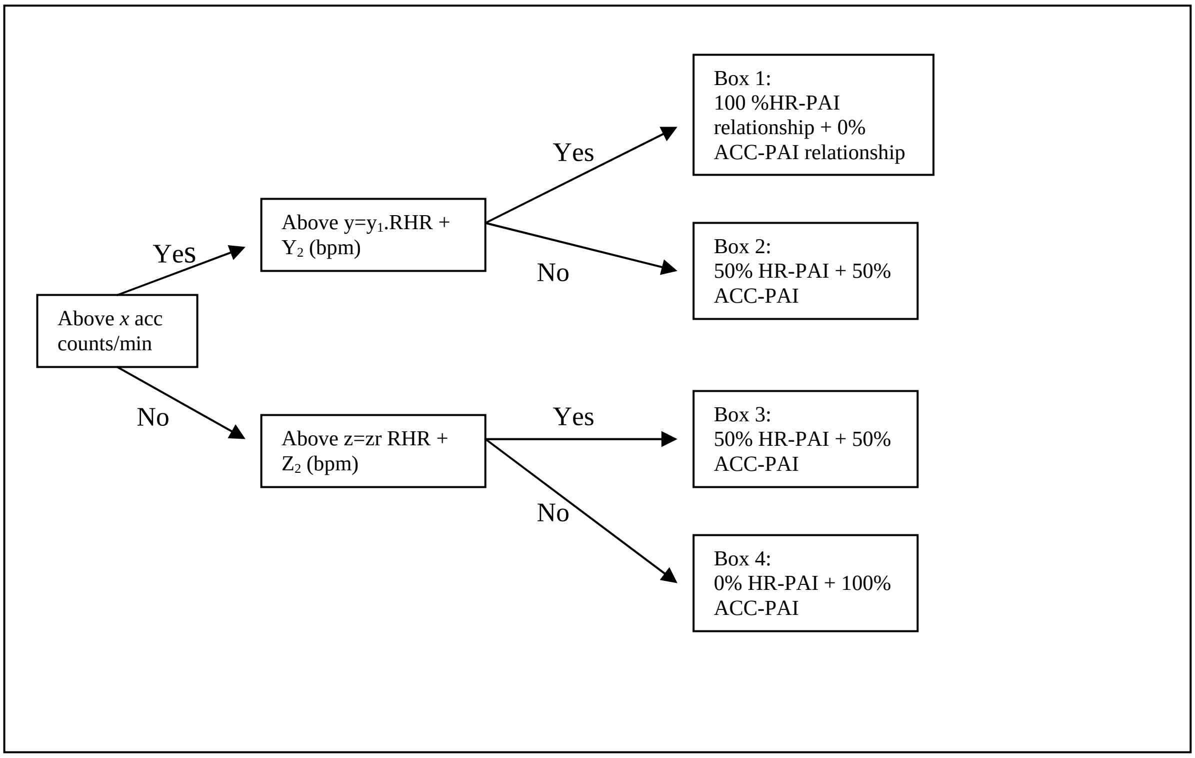

Figure 3-4. The branched equation model.
X – Used to discriminate between activity and no activity
Y – Used to discriminate between walking and running
Z – Used to discriminate between raised HR due to some 'true' activity in the presence of 'no' activity, (as set by X).
ACC – acceleration, PAI – physical activity intensity, HR – heart rate, RHR – resting heart rate, bpm – beats per minute.
ACC-PAI – the relationship between accelerometry and physical activity intensity
HR- PAI – The relationship between heart rate and physical activity intensity.
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The branched equation model works by using the relationships between HR, ACC and physical activity intensity (PAI) where PAI is the factor by which total energy expenditure exceeds resting energy expenditure, and therefore requires measurement or estimation of resting energy expenditure (REE) and sleeping heart rate (SHR). The AHR software program contains group based calibrations for ACC-PAI and HR-PAI based upon laboratory tests in healthy adults (188), and children (187). However calibrations can also be performed to obtain individual ACC-PAI and HR-PAI relationships, which enhance the accuracy of the AHR and take the form of graded treadmill tests or an inbuilt graded step test.

3.5.1.4.2 AHR placement

The AHR is worn on two ECG electrodes placed across the chest. 3M Red Dot 2239 monitoring electrodes (3M UK Plc, Bracknell, UK) for long term monitoring were used to attach the AHR to the skin following skin preparation. The participants were provided with tissue and asked to gently ‘rub’ the area for the removal of any residue and to ensure adequate adhesion. Electrodes were then placed on the participant with one placed below the level of the apex of the sternum in the middle of the chest and the other horizontally across the pectoralis muscle as shown below (position 1).

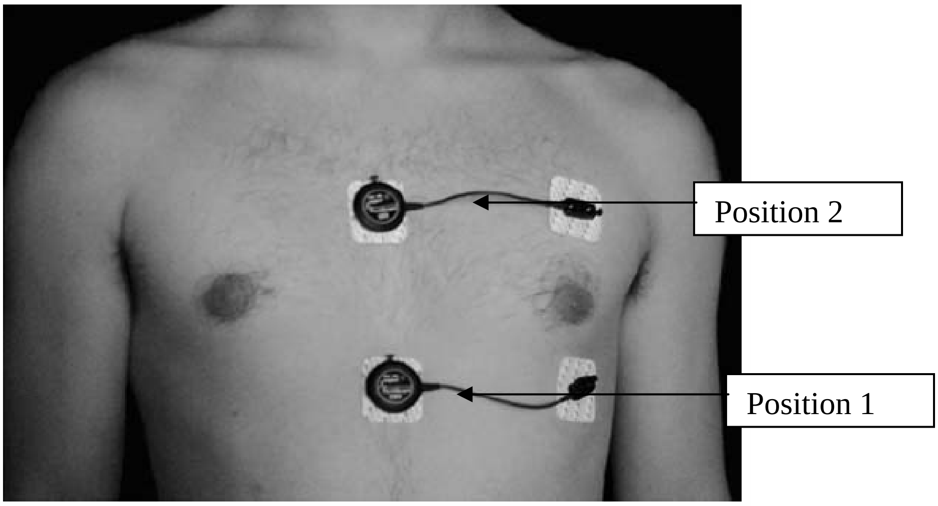


Figure 3-5. Placement of the Actiheart.

In some cases, excess adiposity around the midriff affected the placement of the electrodes and if this was the case, position 2 was used, with one electrode placed level at the third intercostal space and the other horizontally across the pectoralis muscle. Both AHR placement positions have been validated in adults (189).

3.5.1.4.3 The signal test

Following correct electrode placement upon the participant, a 5 minute signal test was initiated. The signal test measures the amount of the R wave signal that is being picked up by the AHR and the level of noise being detected, failing the recording if the noise level is deemed to be too high or the R wave too low. If the recording fails, it is necessary to check the placement and impedance of the electrodes and perform another signal test until the recording is deemed appropriate. The signal test allows for the strength of the heart rate recording to be checked prior to initiating a long term recording.

3.5.1.4.4 The step test

Once the AHR placement is appropriate, participants performed an 8 minute progressive step test to obtain individual HR-PAI and ACC-PAI slopes . Briefly participants were instructed to step up and down a 215mm high step with increasing frequency as dictated by a drum beat or voice command. Stepping speed commenced at 15 body lifts/min in the first minute and increased to 33 body lifts/min by the 8^{th} minute. The test was terminated earlier if HR exceeded 90% of age predicted maximum or if the participant was unable to maintain the prescribed step frequency. Upon test termination, participants were asked to sit quietly for 2 minutes whilst HR recovery was recorded. This allowed for individual HR-PAI and ACC-PAI slopes to be obtained then saved into the software program.

3.5.1.4.5 Lifestyle physical activity measurement

The AHR was set to record in long term mode with 1 minute epochs for 5 days of measurement, as 5 days of habitual physical activity measurement has been shown to be sufficient to gain an accurate estimation of physical activity in children and adolescents (53). The AHR was placed on the participant's chest at the end of the baseline visit, after which they were asked to continue wearing the AHR for the next 5 days. Participants were informed that the AHR was waterproof and asked to wear the AHR at all time including overnight. Replacement ECG electrodes were provided and participants and their parent/guardian were shown how to reattach the electrodes and the correct placement of the AHR.

3.5.1.4.6 Analysis of the AHR measurement

After 5 days of measurement the AHR was returned to the investigator and data downloaded. Sleeping HR was averaged across the 5 days and measured resting energy expenditure (REE) was inputted into the individual calibration. The advanced energy expenditure mode was used for analysis with the energy model selected as 'Group Cal/Step HR' to include the individual slopes obtained during the step test. The physical activity energy expenditure (PAEE) measurement was selected in metabolic equivalents (METs), and all data exported into an excel spreadsheet. A macro was written which could disseminate the 5 days worth of measurement into specific outcomes. PAEE was summed to give a daily PAEE, which was then added to REE to give a value for total energy expenditure (TEE). Total activity counts were summed, as was the total number of samples deemed to be 'ok' by the software allowing for the time not worn to be calculated. The software identifies the data as 'ok' 'recovered' and 'lost' depending upon the strength of the signal however for the purpose of this study only those recordings deemed 'ok' were included. If the AHR had been worn for less than 1000 minutes (16hours), that particular day was excluded from analysis, and any participants who had less than 3 complete days of measurement were also excluded. A further point of interest was the amount of time participants spent in physical activity of different intensities defined by MET score. One MET is defined as the ratio of a person's working metabolic rate relative to the resting metabolic rate, with one MET the equivalent of energy expenditure at rest, assumed to be 1kcal/kg/hr (190). As there was an accurate measurement of REE, MET scores were calculated as a function of rest; MET = PAEE/REE. MET scores are used to differentiate between intensities of physical activity with anything between 3-6MET's defined as moderate intensity and anything greater than 6MET's, vigorously intense. The macro was designed to differentiate between time spent in different intensity activities, as well as counting the number of minutes spent in bouts of activity in the different intensities that either exceeded 1 minute, 10 minutes or 30 minutes in duration.

3.5.1.5 Subjective assessment of physical activity

Participants also completed the physical activity questionnaire for adolescents (PAQ-A) (191), a modified version of the International physical activity questionnaire (IPAQ). The PAQ-A has previously been validated in adolescents (191;192) and asks participants to recall their participation for the previous 7 days. The scores are summed and give a person an average score, allowing for increases in PA to be monitored.

3.5.1.6 Cardiorespiratory fitness

All participants completed a graded exercise test to volitional exhaustion to determine cardiorespiratory fitness, assessed by means of maximal oxygen uptake (VO_{2MAX}), and maximal heart rate (HR_{MAX}). Physical fitness is defined as a set of attributes that people have or achieve that relates to the ability to perform physical activity, and encompasses body composition, lung function and cardiorespiratory fitness. Cardiorespiratory fitness is usually defined in terms of maximal oxygen uptake (VO_{2MAX}) which represents the maximum rate at which an individual can consume oxygen. Maximal exertion is characterised by a respiratory exchange ratio (RER) >1.05, a HR which exceeds 90% of age predicted maximum and a plateau in VO_2 despite further increases in workload, however there is evidence to suggest many children fail to reach this plateau (193), in which case the peak VO_2 (VO_{2PEAK}) reached during the test is used.

3.5.1.6.1 Fitness assessment

Participants were asked to refrain from vigorous intensity exercise for the 24hours prior to the test, and to refrain from the consumption of food and drink other than water for the previous 3 hours. All tests were performed in the metabolic lab within the CRF with temperature maintained at 20°C. A Lode Corival cycle ergometer (Cranlea, UK) with an extra large saddle was used for all fitness assessments alongside an Oxycon Pro (Cardinal Health, UK) indirect calorimeter for continuous breath by breath measurement of VO_2, VCO_2, and RER. The Oxycon oxygen and carbon dioxide sensors were calibrated prior to every testing session using gases of known concentration (5% O_2, 16% CO_2). The volume sensor was also calibrated using a 3L syringe. A noseclip was worn to ensure that inhalation and exhalation occurred only though the mouthpiece. HR was continuously measured using a radiotelemetry HR monitor (Polar Vantage NV, Kempele, Finland). Prior to the participant commencing the test, they were familiarised with all equipment and procedures and seat height, handlebar height and crank position were adjusted accordingly to ensure participant comfort.

3.5.1.6.2 McMaster cycle test

The McMaster cycle protocol was followed which is a recommended protocol for youth because it is based upon the height of the participant and uses a gender specific workload (194). For all participants, cycling rate is maintained at 50rpm, with initial work load and work load increments decided by the height of the child.

Height, (cm)	Initial load, (watts)	Increments, (watts)	Duration, (min)
<120	12.5	12.5	2
120-139.9	12.5	25	2
140-159.9	25	25	2
>160	25	50 (boys) 25 (girls)	2

Table 3-2. The McMaster cycle test protocol.
ACSM guidelines for exercise testing and prescription, 7th ed.

Participants were encouraged to exercise until volitional exhaustion unless the participant experienced dizziness, nausea or an excessive rise in HR> 200bpm in which case the test was terminated. Every minute throughout the test, participants were asked to rate their level of perceived exertion (RPE) using a pictorial Borg scale (195). Following termination of the test, workload was gradually decreased and participants were encouraged to maintain cycling with no resistance for up to 5 minutes, during which time HR was monitored.

3.5.1.6.3 Data analysis

Breath by breath measures of VO_2, VCO_2 and VO_2 adjusted for body weight were obtained for the duration of the test. These values were then averaged for every 2 minute stage of the test and plotted against HR, also averaged for every stage. If at least one of the above named criteria for VO_{2MAX} had been attained, VO_{2MAX} was recorded as the highest value reached. Alternatively, the average of the two highest values was taken as VO_{2PEAK}. It has been argued, that submaximal indices of fitness may be a more appropriate outcome measure in children and adolescents largely due to the difficulties in obtaining maximal effort in this population, (130), and therefore the submaximal index of a HR at workloads of 50W and 100W were also obtained. VO_2 was expressed in absolute terms (l/min), adjusted for body weight (ml/min/kg) and also adjusted for fat free mass (ml/min/kg/FFM) allowing for the effects of body composition to be examined.

3.5.2 Secondary Outcomes

3.5.2.1 Psychological well-being

Previous research has identified evidence for significant impairments in the psychological functioning of obese children and adolescents with reduced self-esteem, depressive symptoms, and body dissatisfaction contributing to an overall poor health related quality of life (134;134;196). A psychological questionnaire package was collated with the help of Professor Joan Duda from the School of Sport and Exercise Sciences at the University of Birmingham. Participants were asked to complete six different questionnaires alone, with the principle researcher (CF) on hand to assist and answer questions where necessary. Answers to all questionnaires took the form of likert scales, and the questionnaires took about 20 minutes to complete.

3.5.2.1.1 General Self-worth

The General Self Worth subscale of the Self-description Questionnaire (SDQII) was developed based upon the Rosenberg 1985 Self-esteem scale and has been demonstrated to be a valid and reliable measure of self-worth (coefficient of alpha: 0.80) (196). Children were asked to respond to 13 items which had been amended to be suitable for children on a 6 point Likert scale. The Cronbach's alpha within this sample was 0.73.

3.5.2.1.2 Positive and negative affect

The brief measure of positive and negative affect scale (PANAS) (26) provides independent measures of positive and negative affects and has been validated in the general UK adult population (197). Children were asked to respond to 9 items which measured positive affect on a 5 point Likert scale. Positive affect (PA) represents the extent to which an individual experiences pleasurable engagement with the environment and is characterised by emotions such as enthusiasm and alertness (197). Negative affect (NA) was measured by response to 11 items on a 5 point Likert scale and represents subjective distress and unpleasurable engagements. High NA is characterised by a number of aversive mood states such as anger, guilt and fear whilst low NA is a state of calmness and serenity. In the current study, PA and NA were tested for reliability with PA achieving a Cronbach's alpha of 0.854 and NA 0.636.

3.5.2.1.3 Social Physique Anxiety

The Social Physique Anxiety scale (SPA) measures social physique anxiety, defined as the degree to which a person becomes anxious in social settings when they perceive their physique to be being negatively evaluated (198;199). A modified 9 item version of the 12 item Social Physique Anxiety scale was used with responses scored on a 5 point Likert scale with higher scores indicating a greater degree of Social Physique Anxiety (200). The Cronbach's alpha for the present sample was acceptable at 0.796.

3.5.2.1.4 Body Esteem

Feelings about ones own physique can be differentiated from feelings about ones general appearance and therefore the Body Esteem Scale for Adolescents and Adults (BESAA) was used to tap the three main factors associated with body esteem. General feelings about ones appearance (BE-appearance), weight satisfaction (BE-weight), and evaluations attributed to others about ones body and appearance (BE-attribution) were all assessed by the BESAA, which asked participants to rate how often they agree with a series of 23 statements using a 5 point Likert scale ranging from 'never' to 'always'. The BESAA has previously been validated in large samples (200). Reliability for each subscale was tested using the Cronbach's alpha and found to be 0.741 for the attribution scale, 0.61 for the appearance scale and 0.623 for the weight scale.

3.5.2.1.5 Behavioural Regulation in Exercise

Previous research grounded in the self-determination theory has shown that exercise behaviour becomes more internalised as a person becomes more self-determined, suggesting that when the three basic psychological needs are met self-determined forms of motivational regulation guide behaviour and well being outcomes ensue. Therefore the Behavioural Regulation in Exercise Questionnaire (BREQ) was developed to identify these types of behaviours (201), and then modified in 2004 to include a measure of amotivation (202). The integrated regulation subscale from the Exercise Motivation Scale is also included (203). The questionnaire consisted of 23 questions scored on a 5 point Likert scale (from 'not true for me' to 'very true for me'). The questionnaire assessed 6 behaviour types, amotivation, external regulation, introjected regulation, identified regulation, intrinsic regulation and integrated regulation, with additional assessment coming from the calculation of the Relative Autonomy Index (RAI). The RAI is a single score derived from the subscales that gives an index of the degree to which a person feels self-determined. A Cronbach's alpha reliability coefficient was computed for each of the 6 factors, amotivation (0.729), external regulation (0.738), introjected regulation (0.597), identified regulation (0.576), intrinsic regulation (0.486), and interjected regulation (0.627).

3.5.2.1.6 Intrinsic Motivation

The interest/enjoyment subscale from the Intrinsic Motivation Inventory is considered the self-report measure of intrinsic motivation and assesses interest and enjoyment in exercise (204) . Participants respond to 7 questions (e.g. Exercising is fun to do) on a 5 point Likert scale. The Cronbach's alpha was 0.532.

Amotivation is a state lacking any intention to engage in a behaviour and is a completely non self-determined form of regulation.
External regulation involves engaging in a behaviour only in order to satisfy external pressures or to achieve externally imposed rewards.
Introjected regulation involves the internalization of external controls, which are then applied through self-imposed pressures in order to avoid guilt or maintain self-esteem.
Identification involves a conscious acceptance of the behaviour as being important in order to achieve personally valued outcomes.
Integrated regulation concerns the assimilation of identified regulation so that engaging in the behaviour is fully congruent with one's sense of self.
Intrinsic regulation involves taking part in an activity for the enjoyment and satisfaction inherent in engaging in the behaviour itself.

3.5.2.2 Resting Energy Expenditure (REE)

Resting energy expenditure represents the amount of calories that would be used by a person in a 24 hour period if they remain rested and is highly variable between participants, with factors such as gender, age, body composition, and physical activity all contributing. The gold standard for measurement of resting energy expenditure, direct calorimetry, involves measuring heat production of the person over a specific period of time but is expensive and impractical to use. Indirect calorimetry is therefore often used as a substitute.

3.5.2.2.1 Indirect calorimetry

Indirect calorimetry (IC) was first developed by Lavoisier in 1784 and makes indirect estimates of the body's heat production through changes in the amount of oxygen (O_2) consumed and carbon dioxide (CO_2) produced. IC measures the respiratory exchange between O_2 consumption and CO_2 production during metabolic needs. The assumption is made that during aerobic oxidation processes, the amount of heat produced is proportional to the quantity of oxygen consumed. Therefore using the known, relative amounts of CO_2 and hydrogen oxidised, a known value of heat production is obtained. Using the equations developed by DeWeir, these values are then translated into a value of energy expenditure, (205). An Oxycon Pro (Cardinal health, UK) open circuit indirect calorimeter was used throughout to continuously measure O_2 consumption and CO_2 production. Concentrations of O_2 in inhaled and exhaled air were determined using a polygraphic analyser and concentrations of CO_2 using an infra red analyser. Prior to use, the Oxycon pro was calibrated using gases of known concentration (16% CO_2 and 5% O_2), whilst the flow meter was calibrated using a 3L syringe. All resting measurements were performed using a ventilated hood (figure 3.6).

Figure 3-6. The ventilated hood.

Room air was continuously drawn through the ventilated hood at a rate of 40L/min to ensure CO_2 was cleared from inside the hood. Respiratory gases were sampled at 30 second intervals.

3.5.2.2.2 Resting energy expenditure

Participants were asked to report to the CRF at 8.30am following an overnight fast and having refrained from participation in vigorous physical activity for the previous 24hours. Upon arrival, participants were asked to familiarise themselves with the surroundings and to make themselves comfortable on the bed. This was followed by a 15 minute rest period. The ventilated hood was then placed over the participant's head and the resting measurement commenced for 30minutes. Participant's were allowed to watch a non emotive DVD and were asked to remain as still as possible for the 30minute measurement. Previous research has suggested participants need 15minutes to acclimatise to the hood and therefore the first 15 minutes of measurement were discarded from the analysis.

3.5.2.3 Data analysis

Continuous measures of VO_2, VCO_2, RER and energy expenditure (EE) were recorded. The 1st 15 minutes of measurement were discarded. Values for the final 15minutes were averaged and used as resting energy expenditure.

3.5.2.3 Dietary Intake

Dietary intake is notoriously difficult to measure accurately as self-report methods such as diaries and food recalls rely on the person's ability to recall specific information. In obese populations, there is additional risk of bias from the common under-estimation of food intake (23).

3.5.2.3.1 24hour recall

The 24 hour recall involves participants recalling every item of food or drink other than water in the previous 24 hours and has been shown to be a valid estimate of energy intake in adolescents (206), with accuracy increasing when the questionnaire is interviewer led, using prompts such as the '*Photographic Atlas of food portion sizes'(207)*. The 24hour recall was performed by the principle researcher using the food atlas to gauge portion sizes, following the guidelines recommended by the US Department of Agriculture (http://www.csrees.usda.gov/).

3.5.2.3.2 Three day food diary

A 3 day food diary asks participants to record all food and drink, other than water, they consume for a 3 day period. Instructions were provided which asked participants to record all food items including brand names, quantities and cooking methods.

3.5.2.3.3 Analysis

Microdiet version 2 (University of Salford, UK) was used to analyse both the 24hour and the 3 day diet diary. Quantities and types of foods and drinks consumed and reported were entered into Microdiet and analysed for total energy intake (kcal/day), total carbohydrate intake (sugar & starch; kcal/day) total fat (SFA, MUFA & PUFA; kcal/day), total protein (kcal/day) and sodium intake (mg). Any days where energy intake was reported to be less than 1000kcal were excluded from analysis. All other days were averaged so dietary intake was reported as average daily intake. The prevalence of under reporting was assessed by calculating the ratio between REE and reported intake (208).

3.6 Exercise Intervention

Upon completion of all baseline assessments, all participants were provided with a copy of the Dance Factory (Codemasters, UK) dance mat game for the playstation along with a Dance Factory dance mat. If necessary a Sony Playstation 2 (Sony, USA) was provided until the end of the intervention. The Dance Factory mat and game were demonstrated to the participants including how to upload music into the game. They were then instructed to perform dance mat exercise on 4 days of the week for 12 weeks, for a minimum of 20minutes at a time. A diary was provided which asked participants to record their participation in dance mat exercise, including space for them to rate the perceived exertion of the exercise. At the end of every week, participants were asked to rate how well they thought they had done with the exercise. Throughout the 12 week period, participants received weekly phone calls or emails to check on progress and to ensure there were no technical problems.

3.6.1 Energy expenditure of dance mat exercise

All participants had their heart rate, VO_2 and energy expenditure (EE) responses to dance mat exercise assessed. This was to ensure standardisation of the competence of participants. All participants completed the same three consecutive dances on the medium mode of difficulty (duration ~12minutes). Heart rate was continuously assessed using a radiotelemetry HR monitor (Polar Vantage NV, Kempele, Finland). Breath by breath expired air samples were continuously measured using an Oxycon Pro indirect calorimeter (Cardinal Health, UK) connected to a face mask worn by the participant. Prior to testing the Oxycon was calibrated using gases of known concentration and a 3L syringe. Once the VO_2, VCO_2 and EE values had reached steady state, they were averaged for every minute of exercise and plotted against HR, also averaged for every minute. Resting and maximal values of VO_2 were used to calculate $VO_{2RESERVE}$ using $VO_{2RESERVE}$: $VO_{2MAX} – VO_{2REST}$. VO_2 during dance mat exercise was then expressed as a percentage of $VO_{2RESERVE}$, and heart rate was expressed as a percentage of HR_{MAX}. VO_2 scores were also converted into Metabolic equivalents (MET). One MET is the energy expenditure of rest normally assumed to be 3.5mlO_2/min/kg. However resting energy expenditure has been directly measured in this population and therefore METs were calculated as VO_2/REE. The procedure was kept consistent for all participants including songs used and level of difficulty.

3.6.2Six week assessment

Participants returned to the CRF after 6 weeks of dance mat exercise. Body weight, height and BMI were recorded and body composition was measured. Participants were set up with an AHR monitor for 5 days of lifestyle physical activity measurement. The PAQ-A was performed, and participants completed a 24 hour recall and 3 day food diary for assessment of dietary intake. Adherence to the exercise intervention was checked through the diary and participants were encouraged to maintain their exercise participation.

3.6.3Twelve week assessment

After 12 weeks, participants returned to the CRF for the final time for assessment of all outcome measures. Adherence to the exercise intervention was once again assessed using the diary and through the AHR readings.

3.7 Statistical analysis

All data was checked for normality using the Shapiro Wilk test. Data that was not normally distributed was either log transformed or tested using non parametric statistics. Non parametric statistics are expressed as medians and ranges whilst parametric data was expressed as means and standard deviations. Detailed explanations of statistics used can be found in the methods sections of each experimental chapter.

4 CHAPTER 4. A DESCRIPTION OF THE METABOLIC AND ENVIRONMENTAL DETERMINANTS OF OBESITY IN CHILDREN AND YOUNG PEOPLE.

4.1 Abstract

Objective: To fully describe the cohort of obese children and young people studied in this PhD thesis. Furthermore this chapter aimed to examine the lifestyle behaviours of obese children compared to lean to identify potential determinants.

Participants: 45 obese children and young people (male = 20) aged 9-18 years with BMI > 95th centile and 15 lean children (male = 6).

Procedure: All children underwent measurement of body composition, physical activity, physical fitness, and dietary intake. Measurement of resting energy expenditure and metabolic health was performed in a sample of the lean and obese children.

Main outcome measures: Body composition, cardiovascular fitness and objectively measured physical activity between lean and obese. Ethnic differences were also explored in relation to lifestyle differences.

Results: Obese children were significantly more obese with average body fat values of 39.6 % and 44.4% in the boys and girls respectively compared to 19.9% and 26.3 % in the lean boys and girls respectively. Participation rates in regular physical activity were lowest for obese girls and highest for lean boys. Sedentary behaviours were highly prevalent accounting for approximately 20 % of the obese children's time. There was evidence of ethnic differences in body composition, and physical activity which warrant further investigation.

Conclusions: The obese children are significantly different from their lean peers in terms of body composition, physical activity and fitness. The levels of fitness observed were similar to those previously seen in 70 year old adults providing evidence for the significant impact obesity has on quality of life.

4.2 Introduction

The last 20 or 30 years has seen a dramatic increase in the prevalence of overweight and obesity in both adult and child populations. Current estimates place around 30% of the UK 11-18 year olds as either overweight or obese defined using age and gender appropriate body mass index standard deviation curves (209). In adults, overweight and obesity are defined using body mass index cut off points identified by the World Health Organisation of >25kg/m^2 and >30kg/m^2 for overweight and obese respectively (210). Additional BMI cut off points exist for the diagnosis of more severe forms of obesity with BMI > 35kg/m^2 considered to be class 2 obesity and a BMI >40kg/m^2 is class 3 or morbid obesity (211). The increasing prevalence of overweight and obesity has been accompanied by escalating numbers of people with morbid obesity (BMI > 40kg/m^2) who carry excess risk for obesity related complications such as type 2 diabetes and cardiovascular disease. In Northern America the prevalence of morbid obesity in 2003-2004 was estimated at 2.8% in men and 6.9% in women, equating to approximately 9 million people, a drastic increase from the 1.7% observed in 1994 (2). In childhood and adolescence the criterion for identifying extreme forms of obesity is less clear with differing BMI cut points used for differing purposes. In Northern America age and gender appropriate BMI SDS values are compared to growth charts compiled in 2000 by the Centre for Disease Control (CDC) with any child exceeding the 85th percentile considered overweight and any child exceeding the 95th percentile considered obese (212). In Europe the International Obesity Task force (IOTF) cut off points based upon age and gender appropriate BMI SDS percentiles are used with cut off points identified linked to an adult BMI of 25kg/m^2 for overweight and 30kg/m^2 for obese (9). Using the British 1990 Growth reference data and the IOTF definition for overweight and obesity, BMI percentile cut off points for obesity in UK children are identified as 99.1 and 98.8 for boys and girls respectively, or BMI

SDS values of 2.37 and 2.25 respectively (9;182). Although the measurement of BMI is limited by an inability to detect fat and fat free mass and hence adiposity, in obese children BMI SDS has been shown to be consistently associated with excess adiposity and the presence of disease risk factors (213). In addition, over time BMI SDS was found to most accurately predict changes in adiposity and is therefore suitable to be used as a measure of obesity in population studies (13). Cross sectional analyses of a cohort of 5-17 year olds in the USA examined the associations between BMI for age, cardiovascular disease risk factors and also longitudinally assessed the associations with adult obesity (213). In the sample of 2392 children, 2 % were found to have a BMI>99th percentile for age and gender. The prevalence of multiple risk factors increased with BMI, rising from 6% at the 90th percentile to 33% at the 99th percentile however these associations were markedly nonlinear with substantial increases only occurring at very high BMI's. Using a BMI SDS cut point of >98th percentile is likely to identify children and adolescents with more extreme forms of obesity and a higher risk of obesity associated complications.

The consequences of obesity are well defined and include physical, psychological and social impairments, all of which have been shown to track into adulthood in a similar pattern to the tracking of obesity (20). The tracking of obesity into adulthood increases with age; at age 3-5 years, less than 20% of boys and between 20 and 40% of girls will become obese adults, increasing to over 60% at age 12years for females and age 17years for boys (20). The causes of obesity are multifaceted and include factors such as diet, physical activity and participation in sedentary behaviours with the fundamental cause being a chronic positive energy balance occurring as a result of an imbalance between intake and expenditure. In adulthood obesity arises over a number of years through minor imbalances between energy intake and expenditure. In childhood when fast gains in BMI are observed, imbalances may need to be substantial in proportion to a child's physiological energy intake requirements. In addition healthy growth and development require an increased macronutrient and protein intake and increased energy expenditure and therefore in childhood energy requirements are increased above those of adults (214).

Longitudinal studies of growth and development can be used to examine the levels of energy imbalance that will lead to weight gain. For example a study of one year changes in weight and body composition performed in Hispanic children and adolescents found that an average weight gain of 6.1kg or 13% could be explained by an excess energy intake of 244kcal/day or reduction in physical activity of 60minutes of walking a day (215). However an alternative study found that children who became overweight over a 4 year period had an energy imbalance of just 46-72kcal/day equivalent to 100-140kcal excess calories (31) suggesting that very minor changes in intake and expenditure can build up and cause increases in weight that can lead to pathology over a period of time. A 10 year study of children aged 2-7 years found excess weight gain of 0.43kg/year to have been largely prevented by a reduction in the energy gap of 110-165kcal/day (216). However for overweight 12-17 year olds a 10 year excess weight gain of 26.5kg was explained by an average energy imbalance of between 678 and 1017kcal/day. The lack of consensus regarding the level of energy imbalance required to produce unhealthy weight gain is likely due to the difficulty in obtaining accurate measurement of energy balance. Measurement techniques for both the assessment of physical activity and energy expenditure and dietary intake are liable to limitation. Dietary assessment often involves self-report or interviewer administered questionnaires and previous research has revealed a tendency of obese children to under report dietary intake to a greater degree than lean children (26;217). There is evidence for a converse tendency to over report participation in physical activity and energy expenditure in obesity which makes accurate measurement of energy balance extremely difficult (218). The quantification of energy balance is crucial not only for determining the positive imbalance required for obesity development but also the converse negative imbalance required for weight loss. Some suggest that an imbalance of just 100kcal/day would be sufficient to prevent unhealthy weight gain in 90% of the US population whilst other authors have proposed a significantly greater total negative energy balance of 3500kcal required for 1 pound of fat loss (21;219).

In the UK significant ethnic differences in obesity and associated comorbidities have been observed in adults and healthy children, with those of South Asian (SA) origin experiencing a higher risk and prevalence of obesity, cardiovascular disease (CVD) and type 2 diabetes(82;88). Numerous factors have been suggested to contribute to this ethnic difference for example family history and metabolic programming (changes to the metabolism that happen in utero) however the contribution of lifestyle factors such as diet and physical activity are poorly understood.

4.3 Aims

The aims of this chapter are to provide a detailed description of the cohort studied throughout this PhD thesis. All children and adolescents who attended the Birmingham Children's Hospital and were found to have a BMI SDS that exceeded the 95th percentile for their age and gender were invited to participate. This chapter will describe the physical characteristics of participants and how these relate to the normal population as well as reviewing the prevalence of excess adiposity and obesity related complications. The chapter will also summarise the lifestyle of participants including an objective measurement of physical activity and self reported dietary intake and sedentary behaviour. Lifestyle factors will be related to measures of body composition with correlation analysis used to estimate predictors of physical activity, diet and sedentary behaviours. Furthermore any potential ethnic differences in physical characteristics, and lifestyle behaviours will be examined.

4.4 Methods

4.4.1 Participants.

45 children and adolescents who fulfilled the inclusion criteria (BMI SDS > 95th percentile for age and gender and were willing to provide informed consent) participated in the present study. All children and adolescents who participated in the initial baseline assessments were invited to participate in the full exercise intervention study (Chapter 5), with 34 of the 45 (76%) choosing to take part. In addition, 15 children and adolescents were recruited through local health and fitness clubs to act as a lean, control cohort. Recruitment took the form of poster and leaflet advertisement. All participants attended the Clinical Research Facility at the Birmingham Children's Hospital where they completed the following assessments, all of which are described in detail in Chapter 3, General Methods.

4.4.2 Measurements

4.4.2.1 Physical characteristics

- Height
- Weight
- Body fat %
- Fat mass (FM)
- Fat Free Mass (FFM)
- Waist circumference
- Resting heart rate
- Resting energy expenditure (Schofield equation and/or measured)

4.4.2.2 Sociodemographic

- Postcode assessment for Index of Multiple Deprivation (IMD)

4.4.2.3 Physical activity

- 5 day Actiheart measurement
    - Activity counts
    - Counts per minute (average counts/time worn)
    - Physical activity energy expenditure
    - Total energy expenditure
    - Moderate to vigorous physical activity (MVPA = >3MET's)
    - % MVPA (percentage of time spent in MVPA)
    - MVPA_Ten (MVPA accumulated in bouts of ten minutes or longer)
    - Physical activity level (PAL = TEE/PAEE)

4.4.2.4 Sedentary behaviour

- Self-report time spent engaged in watching television and playing computer/video games

4.4.2.5 Dietary Intake

- 24 hour recall
- 3 day food diary
- Assessed for calorie intake using Microdiet

4.4.3 Statistical analysis

Data was checked for normality using the Shapiro-Wilk test. Some of the data was not normally distributed and therefore non parametric statistics were used. All data are expressed as medians and minimum and maximum values. The Kruskal-Wallis test was used to test for differences between several independent groups. Mann-Whitney tests were used as Post-Hoc tests to determine where the differences lay. The Bonferroni correction was applied to increase statistical power. Significance was set as $P<0.05$ for the Kruskal-Wallis test and

$P<0.008$ for the Mann-Whitney Post-Hoc with Bonferroni correction ($0.05/6 = 0.008$). Associations between independent factors were examined using Spearman's Rank non parametric correlation coefficient.

4.5 Results

4.5.1 Physical characteristics

The physical characteristics of the participants are summarised in table 4.1.

Table 4-1. Physical characteristics of obese and lean children and adolescents.

	Boys		Girls		Kruskal Wallis Test
Variable	*Obese (n=20)*	*Lean (n=6)*	*Obese (n=25)*	*Lean (n=9)*	*Significance*
Age (years)	13.5 (10.0-16.0)	13.0 (12.0-17.0)	14.0 (9.0-17.0)	15.0 (12.0-18.0)	0.060
Height (m)	1.65 (1.41-1.84)	1.66 (1.51-1.83)	1.62 (1.48-1.73)	1.63 (1.52-1.66)	0.005
Weight (kg)	93.3 (45.4-131)	59.1 (38.8-82.9)[a]	90 (62.2-128)	57 (47.2-76.10)[c]	0.304
BMI (kg/m2)	31.7 (21.5-45.6)	21.2 (17.0-24.7)[a]	32.6 (26.6-48.3)	22.5 (18.9-28.6)[c]	0.000
BMI SDS	3.03 (1.86-3.93)	1.08 (-0.39-1.35)[a]	3.10 (2.02-4.27)	0.80 (-0.86-2.21)[c]	0.000
Body fat %	39.6 (24.2-54.4)	19.9 (14.8-21.4)[a]	44.4 (27.2-56.0)	26.3 (22.1-33.8)[c]	0.000
FFM (kg)	55.8 (32.0-76.5)	46.6 (33.1-67.2)	50.4 (37.7-65.9)	42.7 (36.3-50.4)[c]	0.019
FM (kg)	34.3 (13.4-67.1)	12.0 (5.74-15.8)[a]	38.6 (18.8-65.5)	14.7 (11.0-25.7)[c]	0.000
WC (cm)	104 (79.5-142)	72.5 (68.0-82.0)[a]	101 (83.3-144)	68.0 (62.0-87.0)[c]	0.000
REE (kcal/day)	2033 (1255-2659)	1477 (1148-1865)[a]	967 (727-1720)	684 (602-844)[c]	0.000
RHR (bpm)	75.5 (61.0-89.0)	73.5 (65.0-80.0)	76.0 (59.0-104)	75.0 (68.0-89.0)	0.722
Rank	11.8 (0.64-61.8)	38.8 (15.5-76.9)	14.6 (1.90-99.9)	52.4 (13.1-99.9)[c]	0.000

BMI, Body mass index; BMI SDS, body mass index standard deviations core; FFM, fat free mass; FM, fat mass; WC, waist circumference; REE, predicted REE from the Schofield equation; RHR, resting heart rate; Rank, rank score from the Index of multiple deprivation, the higher the Rank the lower the deprivation.
a – $P<0.008$ versus obese males, b – $P<0.008$ versus lean males, c – $P<0.008$ versus obese females.

There were no differences between groups in median age with an overall range from 9-18 years and median values for obese children of 13.5 and 14 years for boys and girls respectively and for the lean children 13 and 15 years respectively. According to 1990 British reference data, the BMI SDS of all obese children exceeded the 95th percentile for age and gender. In addition, all but 4 of the boys and 3 of the girls exceeded the IOTF criteria for definition of obesity of BMI SDS 2.37 for boys and 2.25 for females (9). The Rank score indicates the level of deprivation, with suggestions that the lean girls are less deprived than the obese girls.

There were significant gender and group differences in the median values for predicted resting energy expenditure obtained using the Schofield equation (220) with the highest REE apparent for the obese boys.

4.5.2 Resting Energy Expenditure

Indirect calorimetry was performed in 34 of the 45 obese and all of the lean participants, as a means of validating the use of prediction equations in this population with the results summarised in table 4.2.

Table 4-2. Measured and predicted resting energy expenditure in a sample of lean and obese participants.

	Boys		Girls		Kruskal Wallis test
	Obese (n=17)	**Lean (n=6)**	**Obese (n=17)**	**Lean (n=9)**	**Significance**
Age (yrs)	13.0 (10.0-16.0)	13.0 (12.0-17.0)	14.0 (9.0-17.0)	15.0 (12.0-18.0)	0.047
Height (m)	1.65 (1.41-1.84)	1.66 (1.51-1.83)	1.63 (1.48-1.71)	1.63 (1.52-1.66)	0.604
Weight (kg)	87.8 (45.4-119)	59.1 (38.8-82.9)	90.8 (62.2-128)	57.0 (47.2-76.10)[c]	0.000
BMI SDS	2.96 (1.86-3.62)	1.08 (-0.39-1.35)[a]	3.32 (2.02-4.27)	0.80 (-0.86-2.21)[c]	0.000
Body fat %	36.1 (24.2-50.0)	19.9 (14.8-21.4)[a]	44.7 (32.4-54.5)	26.3 (22.1-33.8)[c]	0.000
FFM	54.8 (32.0-76.5)	46.6 (33.1-67.2)	54.1 (37.7-65.9)	42.7 (36.3-50.4)[c]	0.045
Schofield REE (kcal/day)	1944 (1255-2451)	1477 (1148-1865)	1012 (727-1853)	684 (602-844)[c]	0.000
Measured REE (kcal/day)	1576 (965-2402)	1658 (1365-2101)	1591 (1161-2024)	1400 (1260-1679)	0.097
Discrepancy (kcal)	345 (¯418-799)	-215 (-236- ¯161)[a]	⁻625 (¯1034-433)	-709 (-835- ¯652.)	0.000

BMI SDS, body mass index standard deviation; FFM, fat free mass; REE, resting energy expenditure. a- P<0.0125 versus obese males, b- P<0.008 versus lean males, c- P<0.008 versus obese females.

The Schofield equation underestimated measured REE in all groups except for obese boys for whom the median discrepancy was positive. The prediction of REE using the Schofield equation was significantly lower for both lean groups with the median value lowest in the lean girls.

Measured REE correlated strongly with FFM in both the obese male participants (r=0.730**, P=0.001) and the lean male participants (r=0.603**, P=0.010) however correlations were much weaker for obese girls (r=0.333, P=0.191) and lean girls (r=0.611, P=0.081). Fat mass was a significant correlate of measured REE in obese males (r=0.603*, P=0.010), lean males (r=0.829*, P=0.042), obese females (r=0.517*, P=0.034) and lean females (0.711*, P=0.032). Previous research has demonstrated FFM to be the major determinant of measured REE, as was observed using regression analysis for all groups. As with previous research, in the majority of participants, FFM accounted for around 80% of the variance in REE signifying the importance of involving FFM in the estimation of REE.

4.5.3 Physical Fitness

34 of the obese participants and all lean children participated in an exercise test to volitional exhaustion to determine peak HR and oxygen uptake (VO_2). The results are summarised in table 4.3.

Table 4-3. Physical fitness in lean and obese participants.

	Boys		Girls		Kruskal wallis test
	Obese (n=17)	*Lean (n=6)*	*Obese (n=17)*	*Lean (n=9)*	*Significance*
HR_{PEAK}	183 (153-200)	186 (173-198)	177 (151-200)	185 (172-200)	0.358
VO_{2PEAK} (ml/min/kg)	24.1 (8.31-43.1)	47.2 (37.0-51.3)[a]	19.6 (10.7-30.3)	34.5 (29.1-42.5)[c]	0.000
VO_{2PEAK} (ml/min/kgFFM)	39.5 (14.0-56.9)	59.2 (43.2-64.7)[a]	32.8 (20.2-55.5)	47.9 (43.1-62.5)[c]	0.000
VO2 (l/min)	2.13 (0.94-3.05)	2.90 (1.43-3.96)	1.81 (0.79-2.33)	2.17 (1.73-2.55)	0.065

a – P<0.05 versus obese males, b – P<0.05 versus lean males, c – P<0.05 versus obese females.

Lean participants had significantly higher levels of VO_{2PEAK} than obese when adjusted for body weight and FFM. Previous research has indicated that differences in fitness between lean and obese children and adolescents can be largely explained by differences in FFM but that isn't the case in the current study (70). There were no significant differences between lean and obese when expressing fitness in absolute terms and not taking body weight or FFM into account.

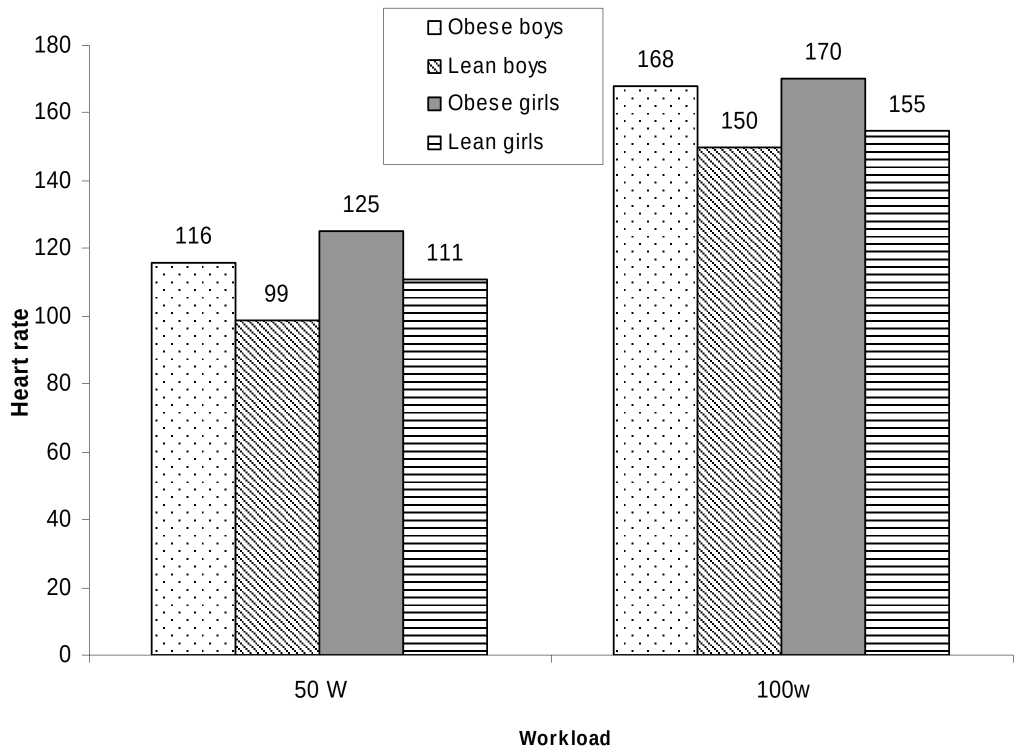


Figure 4-1. Heart rate at submaximal work loads in lean and obese children.

Heart rates at submaximal heart rates were significantly different between lean and obese for both genders. At 50 watts, heart rate was significantly lower for the lean males compared to obese (p = 0.041), whilst for girls the difference was also significant (p = 0.037). At 100 watts, there were also significant differences between groups with both lean boys and girls experiencing lower heart rates, (for boys, P = 0.016, for girls P = 0.030).

4.5.4 Lifestyle factors

4.5.4.1 Physical activity variables

The physical activity variables obtained by 5 days of Actiheart measurement are summarised in table 4.4. Due to the apparent inaccuracy of using the Schofield equation to predict REE, Actiheart data is only summarised for the 34 obese and 15 lean participants who underwent measurement of REE.

	Boys		Girls		Kruskal Wallis test
Variable	Obese (n=17)	Lean (n=6)	Obese (n=17)	Lean (n=9)	Significance
AHR counts (CPM)	48.0 (20.0-105)	69.6 (45.0-119)[a]	35.5 (15.0-48.0)[b]	34.3 (21.0-120)	0.005
PAEE (kcal/day)	763 (269-1756)	898 (535-1412)	587 (193-1156)	652 (336-917)	0.122
TEE (kcal/day)	2411 (1473-3704)	2760 (2220-2968)	2304 (1353-3070)	2123 (1712-2479)	0.042
MVPA (min/day)	56.8 (4.00-229)	181 (72-290)[a]	35.9 (0.00-103)	112 (58.0-186)[c]	0.000
% MVPA (% of time worn)	6.98 (0.33-16.1)	12.6 (5.00-20.0)	2.64 (0.00-8.00)	7.22 (4.10-13.0)[c]	0.002
MVPA_TEN (mins)	5.40 (0.00-41.0)	50.2 (37.0-97.0)[a]	2.00 (0.00-15.0)	11.33 (0.00-40.0)[c]	0.002

Table 4-4**. Physical Activity variables from 5 days of AHR measurement.**

CPM, counts per minute; PAEE, physical activity energy expenditure; TEE, total energy expenditure (PAEE + REE); MVPA, moderate vigorous physical activity; % MVPA, % of time worn; MVPA_Ten, MVPA in ten minute bouts or longer. a - P<0.05 versus obese males, b- P<0.05 versus lean males, c- P<0.05 versus obese female.

Mean physical activity counts per minute were highest for the lean male participants, significantly higher than in the obese males and females despite small numbers. The current guidelines for child participation in physical activity recommend that each child accumulate 60 minutes of moderate to vigorous physical activity on every day of the week (47). On average this guideline was exceeded by all the lean participants, reaching the highest level in the lean males who participated in an average 181 minutes of MVPA every day. MVPA was equated as a percentage of the time worn to allow for differences in time worn. Lean children remained significantly more active when expressed as a function of time worn.

4.5.4.2 Dietary Intake

The average daily dietary intakes of participants are summarised in table 4.5.

Table 4-5. Average dietary intakes.

	Boys		Girls		Kruskal wallis test
	Obese (n=20)	Lean (n=6)	Obese (n=25)	Lean (n=25)	Significance
Energy intake (kcal/day)	1622 (1058-2641)	1781 (1489-2325)	1422 (883-2987)	1487 (1209-2188)	0.116
Fat intake (g)	65.1 (19.1-140)	70.0 (59.0-96.0)	57.1 (6.00-294)	60.0 (36.0-78.0)	0.336
Fat intake (% of diet)	38.1 (11.0-63.0)	38.0 (3.0-52.0)	33.6 (19.0-46.0)	28.0 (23.0-44.0)	0.169
SFA (g)	20.0 (6.0-55.0)	21.0 (9.0-38.0)	19.3 (5.0-51.0)	20.0 (11.0-25.0)	0.947
Sodium (mg)	2027 (1192-3802)	2024 (1481-3291)	1727 (584-4669)	1449 (953-2170)	0.024
Deficit (kcal) (n=34)	767 (374-1669)	739 (409-1380)	815 (-240-1795)	636 (-41.0-1203)	0.471

SFA, saturated fatty acids; Deficit, TEE-Energy intake.
a – P<0.05 versus obese males

The highest energy intakes reported were for the lean males and the lowest median values were in obese girls. There is evidence of significant mis-reporting and therefore the diet data should be treated with caution.

4.5.4.3 Sedentary behaviour

Participation in sedentary behaviours was assessed by self-report time spent engaged in television viewing and playing computer games and are summarised in table 4.6.

Table 4-6. Average times spent in sedentary behaviour.

	Boys		Girls		Kruskal wallis test
	Obese (n=20)	**Lean (n=6)**	**Obese (n=25)**	**Lean (n=9)**	**Significance**
Daily time (mins)	351 (90.0-591)	133 (106-209)[a]	253 (0-523)	180 (85.7-240)	0.000
% sedentary	24.4 (6.00-41.0)	8.61 (7.00-13.5)[a]	17.6 (0.00-36.0)	11.7 (5.56-15.6)	0.000

**p<0.05, lean versus obese*

In both genders lean children spent less time in sedentary behaviours with obese boys spending the most amount of time sedentary (nearly 6 hours/day) and lean boys the least (2 hours/day). Obese boys spent significantly more time engaged in sedentary behaviours when compared to all lean participants.

4.5.5 Correlates and predictors of body composition

Participation in lifestyle behaviours for our sample of 45 obese children and young people has now been described but it is of note to examine how these behaviours relate to body composition. The correlates of body composition parameters are summarised in table 4.7.

Table 4-7. The correlates of body composition in lean and obese children and young people.

	Boys (n=20)						Girls (n=25)					
	Obese (n=17)			Lean (n=6)			Obese (n=17)			Lean (n=9)		
	BMI SDS	**BF**	**WC**	**BMI SDS**	**BF**	**WC**	**BMI SDS**	**BF**	**WC**	**BMI SDS**	**BF**	**WC**
Age (yrs)	-0.050	-0.286	0.652**	0.403	-0.059	0.940**	0.096	0.100	0.052	-0.493	-0.402	-0.529
Rank	0.162	0.110	-0.396	0.435	-0.429	0.116	0.049	0.074	-0.045	-0.683*	-0.717*	-0.683*
AHR counts (CPM)	-0.618**	-0.309	0.179	0.426	0.667	-0.074	0.093	-0.037	-0.119	-0.100	-0.283	0.183
MVPA (mins)	-0.502*	-0.453	0.434	-0.145	0.429	-0.551	0.586*	0.536*	-0.011	0.067	-0.133	-0.033
% MVPA	-0.284	-0.414	0.461	-0.145	0.429	-0.551	0.583*	0.475	0.105	-0.367	-0.567	-0.417
% Sedentary	-0.002	0.205	-0.040	0.464	-0.029	0.058	0.559*	0.276	0.118	0.259	0.100	0.410
Dietary intake (kcal/day)	0.471	0.179	0.175	0.638	-0.429	0.464	-0.272	-0.007	-0.307	-0.633	-0.733*	-0.333
Deficit (kcal)	0.125	-0.034	-0.042	-0.232	0.600	-0.290	0.586*	0.520*	0.155	0.583	0.617	0.433

*BMI SDS, body mass index standard deviation score; BF, body fat %; WC, waist circumference; Rank, index of deprivation rank; CPM, physical activity counts per minute; MVPA, moderate to vigorous physical activity; % MVPA, percentage of time spent engaged in MVPA; % Sedentary, percentage of time spent sedentary; Deficit, difference between dietary intake and TEE. * p<0.05; ** p<0.01*

For both male groups there is a significant relationship between age and waist circumference which is not apparent for girls or for any other measure of body composition. Socioeconomic status was correlated with BMI SDS and BF for lean girls in a negative manner suggesting that a higher SES is related to a lower BMI SDS and BF %. This relationship does not exist for either of the obese groups which may be due to a lower median rank and smaller range exhibited by the obese groups compared to lean.

In boys, participation in physical activity appears to be strongly negatively correlated with body composition suggesting that physical activity participation plays a protective role as has been previously demonstrated (60;221). In the girls BMI was negatively associated with participation in light physical activity and positively associated with sedentary time. This is against expectation and against what was seen for the boys. It may be that the levels of physical activity seen were too low for any observations to be made or that there is a threshold level of MVPA participation below which no protective effects are seen. Alternatively as BMI SDS is a reflection of energy balance, if those who were more active compensated for the increased activity by increasing energy intake, a negative relationship may be seen. Participation in sedentary behaviours is suggested to increase the risk and prevalence of obesity through two distinct mechanisms; a replacement of physical activity and the promotion of increased food consumption. (40). Dietary intake is notoriously difficult to measure accurately and the level of deficit apparent provides support for this. The negative correlation observed between dietary intake and body fat % in the boys demonstrates the inaccuracy of dietary measurement. However there was a significant negative relationship between dietary intake and BF % in the lean girls.

The level of deficit is linked to BMI SDS in the obese girls suggesting that the level of dietary under reporting is linked to obesity.

4.5.6 Correlates of physical activity participation

The key to successful lifestyle intervention is to identify the correlates of healthy behaviours and tailor the intervention to focus on these correlates. Therefore the correlates of participation in physical activity were assessed. There was no apparent correlation between age and any physical activity variable in contrast to previous research which has noted an age related decline in activity (14) in younger children. Socioeconomic status was only correlated with activity in the obese females for whom a higher SES was associated with increased activity.

4.5.7 Ethnic differences

Ethnicity was self-reported by all participants and those who were obese and reported to be of White UK or South Asian inheritance are included in further analysis.

4.5.7.1 Physical characteristics

Physical characteristics of participants grouped by gender and ethnicity are summarised in table 4.8.

Table 4-8. Physical characteristics split by gender and ethnicity.

	White		South Asian		
	Boys (n=12)	*Girls (n=15)*	*Boys (n=8)*	*Girls (n=8)*	*Significance*
Age (yrs)	14.0 (11.0-16.0)	13.0 (9.00-17.0)	12.0 (10.0-16.0)	14.5 (12.0-17.0)	0.149
Rank	11.5 (0.64-62.0)	14.7 (1.90-99.9)	11.8 (2.58-52.5)	16.6 (4.86-62.9)	0.691
Height (m)	1.67 (1.57-1.80)	1.58 (1.48-1.70)	1.63 (1.41-1.84)	1.65 (1.51-1.68)	0.108
Weight (kg)	89.0 (69.6-132)	85.0 (62.2-123)	101 (45.4-119)	90.4 (69.0-117)	0.943
BMI SDS	2.97 (2.14-3.93)	3.06 (2.19-4.27)	3.17 (1.86-3.71)	2.94 (2.02-3.91)	0.878
Body fat %	37.7 (30.4-52.8)	42.8 (27.2-54.3)	41.0 (24.2-54.4)	44.6 (35.3-56.0)	0.513
REE	1964 (1648-2659)	952 (727-1720)	2155 (1255-2451)	964 (1784-1186)	0.004
WC (cm)	102 (85.0-142)	101 (83.0-144)	109 (79.0-132)	103 (88.0-119)	0.994
RHR	76.5 (61.0-87.0)	75.0 (50.0-104)	75.5 (66.0-89.0)	78.5 (72.0-84.0)	0.160

BMI SDS, body mass index standard deviation score; REE, resting energy expenditure; WC, waist circumference; RHR, resting heart rate.
[a] - p<0.05, compared to white boys.

There were no gender or ethnic differences in age, height or weight. There was a trend for girls to have higher levels of body fat.

4.5.8 Lifestyle factors

4.5.8.1 Physical Activity Variables

The physical activity variables obtained from 5 days of Actiheart measurement are summarised in table 4.9.

Table 4-9. Physical activity variables divided by gender.

	White		South Asian		
Variable	Boys (n=12)	Girls (n=15)	Boys (n=8)	Girls (n=8)	Significance
AHR counts (CPM)	43.4 (17.0-92.1)	35.5 (14.6-82.7)	42.6 (18.4-83.0)	32.3 (17.5-50.6)	0.208
PAEE (kcal/day)	703 (104-1157)	592 (193-1156)	936 (405-1756)	647 (468-977)	0.792
TEE (kcal/day)	2633 (2314-3741)	1537 (919-2769)[ab]	2676 (2328-3972)	1658 (1269-1988)	0.000
MVPA (min/day)	51.6 (0.00-132)	49.2 (0.00-186)	94.5 (3.86-229)	37.1 (10.2-93.6)	0.343
% MVPA (% of time	4.47 (0-16.9)	4.63 (0-22.9)	7.74 (0.33-16.1)	3.69 (0.72-15.5)	0.624
MVPA_TEN (mins)	5.16 (0.00-4.75)	1.57 (0.00-12.4)	9.00 (0.00-27.0)	1.79 (0.00-14.6)	0.343

AHR counts, activity counts per minute; PAEE, physical activity energy expenditure; TEE, total energy expenditure; MVPA, moderate to vigorous physical activity; % MVPA, percent of time spent in MVPA; MVPA_TEN, minutes of MVPA in bouts of ten minutes or more; [a] – $p<0.08$, compared to white boys;[b] – $p<0.008$, compared to South Asian boys; [c] – $p<0.08$, compared to white girls.

Girls of both ethnicities were less active than boys. SA boys appear to spend the most amount of time in MVPA with a median value exceeding the Government guideline level of 60 minutes per day. However the small number of SA boys means that the data is likely skewed by a couple of very active boys. All other groups failed to reach the Government guidelines level of MVPA participation, with all groups failing to achieve 60 minutes of MVPA in bouts of ten minutes or more.

4.5.8.2 Dietary intake and sedentary behaviours

Self-reported dietary intake and time spent engaged in sedentary pursuits are summarised in table 4.10.

Table 4-10. Self-reported dietary intake and sedentary behaviours.

	White		South Asian		
	Boys (n=12)	Girls (n=15)	Boys (n=8)	Girls (n=8)	Significance
Dietary intake					
Energy intake (kcal/day)	1578(1058-2641)	1422 (1066-2528)[b]	1728 (1260-2395)	1749 (1145-2987)	0.242
Fat intake (g)	58.0 (19.0-98.0)	57.1 (18.0-294)	90.9 (25.0-140)	75.1 (5.53-139)	0.223
Fat intake (% of diet)	34.4 (12.0-50.0)	33.0 (24.0-46.0)[b]	42.7 (18.0-63.0)	37.3 (21.0-44.0)	0.173
Sodium (mg)	1963 (1192-3802)	1700 (584-3653)	2193 (1781-2787)	1943 (1249-4669)	0.235
Sedentary Behaviours					
Minutes	351 (214-480)	223 (0.00-429)[a]	366 (90.0-591)	274 (90.0-523)	0.014
% Sedentary	24.4 (15.0-33.0)	15.5 (10.0-30.0)[a]	25.4 (6.0-41.0)	19.1 (6.0-36.0)	0.013

a – p<0.008, compared to white boys
b – p<0.008, compared to South Asian boys

The only significant difference in reported dietary intake was between white girls and South Asian boys in terms of both calorie intake and percentage fat intake. However all self-report diet data should be treated with caution.

4.6 Discussion

The aim of this chapter was to fully describe the cohort of obese children and young people who participated in this study. Their physical characteristics and lifestyle behaviours have been described and compared to age and gender matched lean participants and correlates of their characteristics and behaviours have been examined. Potential gender and ethnic differences have also been explored.

In summary obese and lean children and young people differ significantly from one another in terms of body composition and lifestyle behaviours. The Schofield equation was found to be a poor predictor of resting energy expenditure in all children, underestimating to the greatest degree in the lean females. The obese children display signs of impaired metabolic health with approximately 50% exceeding thresholds for TG levels and fasting insulin. Physical fitness was significantly impacted by the presence of obesity with the obese children achieving VO_{2PEAK} values similar to those previously seen in 70 year old adults (223). This is likely due to the low levels of lifestyle physical activity performed by the obese children with them failing on average to achieve government recommendations of participation (224). Participation in sedentary behaviours far exceeded participation in physical activity with the obese boys spending over 6 hours a day engaged in television viewing or personal computer use. It is difficult to draw any conclusions about dietary intake as there are signs of significant under reporting in all children with a massive deficit between energy expenditure and apparent intake. Correlates of body composition, metabolic health and physical activity participation were explored with regards gender and ethnic differences.

4.6.1 Body composition

All obese participants involved exceeded BMI SDS > 95^{th} percentile for their age and gender according to UK 1990 growth reference data, therefore representing the extreme of society. No gender differences in body composition were observed in contrast to previous research which has shown consistently higher body fat in females compared to males (89). It may be that the gender differences are lost at the extremes of obesity. Previous research in healthy children and adolescents within the UK found girls to have on average 3.8% more fat than boys at the age of 5 years increasing to 12.9% by the age of 18 years (89). Pubertal status is known to affect body composition with increases in all aspects of body composition (fat mass, lean mass etc) observed during the period of pubertal growth and development (225). Therefore the wide range of age and hence pubertal status in the current study is likely to influence the body composition parameters and may mask any gender difference that would be apparent if all children were at the same stage of development. Obesity in childhood is also associated with early puberty in females and therefore ideally participants would be grouped according to pubertal status however numbers do not allow for this to be done (226).

All obese participants had a BMI SDS which exceeded the 95th percentile for age and gender with 85% of the children also exceeding the 99th percentile. Using the less conservative cut off point of >95th percentile for age and gender, the current prevalence rate of obesity in the UK is estimated at 20% in 11 year olds, with 30% of 11-18 year olds considered either overweight or obese (3;17). In the current study the 98th percentile for waist circumference and body fat % were exceeded by all obese participants (10;11). A recent study of ethnically diverse, healthy adolescents in the Birmingham area, revealed prevalence rates of overweight or obesity to range from 4-14% depending upon gender and ethnicity (88). On average, white female adolescents had a BMI SDS of 0.42±0.20 and a waist circumference of 68.1±1.50cm whilst the males had an average BMI SDS 0.56±0.20 and waist circumference of 73.4±1.70cm; appreciably lower than for the obese population involved in the current study. When compared to lean children and young people, there were significant differences in all aspects of body composition with body fat % of the obese girls almost double that of the lean participants. The lean children did not differ from obese in terms of age and height however both lean males and females had significantly higher Rank scores which can be interpreted as higher socioeconomic status (SES).

Whilst there was no longitudinal element to the current study, a previous study demonstrated that all children with a BMI SDS >99th percentile were obese as adults with 88% of them having an adult BMI>35kg/m^2, and 65% an adult BMI>40kg/m^2. Children with a BMI>99th percentile were also much more likely to display multiple metabolic risk factors, stressing the importance of treating extreme obesity in childhood to prevent the tracking of obesity and complications across the life course.

The estimate of REE for boys significantly exceeded the value predicted for girls despite no apparent difference in fat free mass, the major predictor of REE. As a result measured REE was recorded for a sample of 34 of the obese and all lean participants. In all groups the Schofield equation proved to be a poor predictor of REE with the level of discrepancy greatest for the lean females. In future studies involving obese participants, it is important that potential differences in body composition and hence FFM are taken into account when predicting REE. In comparison to previous measurement of REE in obese children and adolescents the values obtained in the current study appear similar with an average value of 1548±311 kcal/day observed in obese 11 year olds (227) who had an average FFM of 35.3±10.9kg. Similarly in obese 12 year olds, an average REE of 1687±293kcal/day was observed (228). It is a common misconception that REE is reduced in obesity. A literature review examining the relationship between REE and FFM identified 31 data sets of which 11 were conducted in adolescents (229). On average the range of REE in the adolescents was from 1140-2007kcal/day spanning the median values of 1575 (965-2402) kcal/day and 1591 (1161-2024) kcal/day for obese boys and girls respectively and 1657 (1365-2101) kcal/day and 1400 (1260-1679) kcal/day in the lean boys and girls respectively.

A number of the obese children display metabolic abnormalities such as raised cholesterol and impaired glucose tolerance, which increase the risk of future cardiovascular disease and type 2 diabetes. For many of the parameters there were no correlations with age or body composition, however fasting plasma glucose increased as a function of age and 2 hour glucose increased with increasing BMI SDS and WC. There is evidence to suggest that insulin resistance and glucose tolerance alter during the course of puberty possibly driven by changes in growth hormone which may explain the age association seen here (230). Waist circumference is representative of the level of abdominal obesity and therefore the association with 2 hour glucose indicates that abdominal obesity may increase risk for impaired glucose tolerance as previously observed (125).

4.6.2 Physical fitness

Physical fitness expressed as VO_{2PEAK} adjusted for body mass and fat free mass (FFM) was significantly higher for the lean children compared to obese. There were no differences in fitness when expressed in absolute terms. Within the literature there are discrepancies in the reporting of cardiovascular fitness with some authors choosing to report fitness in absolute terms, some adjusted for body weight and some for fat free mass. As fat free mass is the most important determinant of energy expenditure, and is likely to differ between lean and obese, fitness adjusted for fat free mass is the best representative of absolute ‘fitness’. In the current study, expressing fitness for FFM identified differences between lean and obese which were further highlighted in terms of heart rate at submaximal workloads. Highest values were observed in lean males and lowest in the obese females. VO_{2PEAK} was used as a comparator due to not all children reaching maximal exertion however there were no between group differences in maximal heart rate achieved which would suggest there to be no between group differences in effort and exertion. Previous research has suggested the differences in fitness between lean and obese children to be explained by differences in FFM however this was not the case for the present study (70). Values of VO_{2PEAK} recorded are lower than previously seen in obese children of a similar age and BMI SDS. For example Ekelund et al (2004) using a cycle test to exhaustion found maximal VO_2 values of 36.3±3.60ml/min/kg and 28.4±5.80ml/min/kg for obese boys and girls respectively (70). Additionally a further study of obese children found VO_{2MAX} values of 28.8±6.40ml/min/kg in obese girls and 29.1±7.40ml/min/kg in obese boys (231). In fact the VO_{2PEAK} values achieved by the obese children in the current study were equivalent to those previously observed in 60-65year olds for the boys and 75-79year olds for the girls (232). These chronically low levels of cardiorespiratory fitness will have a profound impact on day to day functioning with tachycardia and premature fatigue occurring during walking and with stair climbing leading to maximal heart and ventilation rates (233).

4.6.3 Physical activity

Participation in moderate to vigorous physical activity in min per day was significantly higher in the lean boys and girls when compared to obese with the highest participation rates in the lean boys. Median values for the lean boys (186min (range 72.0-290)) and lean girls (112min (range 58.0-186)) comfortably exceeded the Government guidelines for MVPA of 60 minutes per day

(224). However both obese groups failed to reach these guideline levels, with the obese boys averaging 56.0 (4.00-229) minutes per day and the girls 36.0 (0.00-103) minutes per day. Participation rates for lean children were more than double those of the obese children in both gender groups, and on closer inspection you can see that at least one obese female participated in no MVPA on average. There may be a recruitment bias in that lean children willing to undergo measurement of physical activity are likely to have higher participation rates than the general population and therefore results should be treated with caution. However the chronically low participation rates observed for the obese children are lower than previously observed in healthy 10 year old children (234). There is a well established age related decline in activity participation which commences at around age 12 years (14), therefore potentially missed by this study. A criterion of >4 METs for MVPA was applied in a large scale study of over 5,500 children aged 11 years, with average participation in MVPA of 19.7 minutes per day. Physical activity intensity is often referred to in terms of Metabolic Equivalents (MET) a measure of how much the energy demands of a particular activity exceeds rest. Moderate intensity activity is usually defined as anything which exceeds 3 METs whilst vigorous activity is greater than 6 METs. Using these classifications and through individual calibration of thresholds required for exercise intensities, accelerometer and heart rate monitor outputs can be converted into periods of time spent in different exercise intensities in order for comparison. Although the threshold MET scores for adult exercise intensity are well established, in children there are discrepancies with some studies utilising the adult guideline and some using a less conservative threshold of 4 METs (60). A review of the best method to assign energy costs to children’s physical activity concluded that the utilisation of adult MET scores was applicable and accurate (235). However as there is an age related decline in REE childhood individual MET scores should be calculated using either an accurate prediction equation or measured values.

In order to overcome the issue of monitoring time, MVPA can be expressed as a proportion of the time worn with obese boys in the present study spending a median of 6.98 (0.33-16.1) % of their time in MVPA and the obese girls 3.22 (0-8.06) %. These values are lower than previously observed in lean (12.7%) and obese (7.40%) 17 year olds and than observed in the lean boys (13 (5-20) %) and lean girls (7 (4-13) %) (221). Previous research has also suggested that for the health benefits of physical activity to be seen, physical activity should be accumulated in bouts of ten minutes or longer and as a result this is stated in current adult US and UK government guidelines (177;224). In children, physical activity is characterised by short bursts of spontaneous activity and recommendations suggest that the guideline level of 60 mins/day can be accumulated through continuous or intermittent activity (224). However it is still of interest to examine the amount of time the obese children and young people spent engaged in MVPA of bouts of ten minutes or longer, and on average across the five days, this value was very low 5 (041) mins/day for the obese boys and 2 (0-15) mins/day for the obese girls. This can be interpreted that on average the boys perform one continuous 10 minute bout every other day whilst the girls only achieved this on one or two of the 5 days of measurement. For the lean children again values were significantly increased with boys averaging 50 (37-97) mins/day and girls 11 (0-40) mins/day. This would suggest that the lean children are participating in more structured activity whilst the MVPA seen in the obese children is an accumulation of lifestyle activity.

Participation in physical activity can be expressed in terms of energy expenditure as a consequence of both the time spent engaged in activity and the relative intensity of the activity performed. Energy expenditure during a given activity is affected by the intensity and the duration of the exercise and also by the body weight of the participant as a greater workload is required for a greater body mass to perform a given amount of activity. As a result values for PAEE in obese adolescents have been shown to be no different to that of lean adolescents, 1003kcal/day for the obese and 955kcal/day for the lean (61). The same study found that despite the absence of differences in PAEE, the obese participated in significantly less MVPA averaging 60 minutes per day compared to the 90 minutes/day attained by the lean group. Similar findings were observed in Hong Kong adolescents who attained an average PAEE of 966±579kcal/day compared to 845±462kcal/day by the non obese, however this study used the heart rate flex method to estimate PAEE and so did not draw any conclusions on the adolescent's participation in MVPA (236). This mirrors what was found in the present study with no differences in PAEE observed between obese and lean males and females despite significant differences in MVPA participation. Previous research has found participation in vigorous physical activity to be related to body fat with children who participated in >40min/day vigorous activity less likely to have high body fat than those who participated in 10-18 minutes (237). The cross-sectional nature of these studies makes it difficult to determine causality although obese children and adolescents are consistently found to have lower levels of participation in MVPA, often failing to reach government guidelines of 60 minutes per day (224). This would suggest that reduced participation in regular activity may be contributing to the excess adiposity although the lack of PAEE difference between lean and obese would suggest that there are additional differences contributing to the development of obesity. For example there may be differences in dietary intake or body composition, differences in energy balance, and differences in the intensity of physical activities. The lack of difference in PAEE and TEE between lean and obese would suggest diet is the main factor in weight development.

4.6.4 Dietary Intake

Self-reported energy intake was highest in lean boys, significantly higher than for obese males and lean females in accordance with previous research which has demonstrated gender differences in energy intake (23). The National Health and Nutrition Survey (NHANES) in the US provides extensive information regarding secular trends in nutrition intake and weight status amongst US children and adolescents. Mean energy intake has changed little since the 1970s despite the dramatic rise in overweight and obesity (23) with recent data suggesting 12-15 year olds consume an average 2315±48.8kcal/day. In addition diets were analysed for the contribution of fat and saturated fatty acids (SFA) with average values of 33.5% of energy from fat and 11.8±0.16% from SFA (23) similar to those seen in the present study. An alternative study of slightly younger girls identified the significant problem of under reporting with over 50% of the girls identified as under reporters (28). The average calorie intake of those identified as under reporters was 1158±292kcal/day compared to the average of the rest of the group1755±396kcal/day. Under reporters tended to be heavier and reported greater unhealthy eating habits. In the present study energy deficit was calculated as the difference between energy intake and expenditure. The average discrepancy between intake and expenditure was 767 (374-1669) kcal/day and 815 (-240-1795) kcal/day for the obese boys and girls respectively and 739 (409-1380) kcal/day and 636 (-41-1203) for the lean boys and girls respectively. If these reported intakes were true, the level of negative energy balance is such that significant weight loss would be expected. Previous research has demonstrated that dietary intake may be linked to participation in other behaviours, for example sedentary behaviours are known to increase dietary intake, and a recent study has demonstrated each hour of physical activity participation to cause an energy increase of 292kcal/day (238).

4.6.5 Sedentary Behaviours

Despite their participation rates in physical activity being much higher than for the girls, obese boys also participated in significantly more sedentary activities averaging nearly 25% of their time engaged in television viewing or computer game use. For both genders lean children spent significantly less time sedentary than their obese counterparts with the lowest levels seen in the lean boys who also exhibited the highest participation rates in MVPA.

When compared to previous studies, the values obtained in the current study are similar. A longitudinal study of over 5,500 children aged 12 years found the average time spent sedentary to be 428±66.4 minutes per day accompanied by low levels of participation in MVPA. The US Academy of Paediatrics has published guidelines related to sedentary behaviours which state children should not participate in more than 2 hours of screen time per day (33). This guideline level was shown to be achieved by just 31% of 9 and 10 year old children (34) however this figure was even lower for obese children in the present study with only 11% of participants, the majority being girls meeting these guidelines.

4.6.6 Correlates of physical activity and body composition

Measures of body composition, physical activity, dietary intake, sedentary behaviours and metabolic health were correlated with one another with the aim to identify potential relationships between factors.

There were apparent gender differences in the correlates of body composition with boys experiencing an age related increase in waist circumference which was not apparent for the girls. Socioeconomic status correlated significantly with BMI SDS and BF % in the lean girls only in a negative fashion such that higher SES was related to lower levels of BMI SDS and BF %. Previous research has demonstrated inconsistent results with regards the relationship of socioeconomic status (SES) to obesity especially in adolescence, probably related to the numerous methods and techniques used to assess SES and deprivation (239). The lean children displayed significantly higher rank scores compared to the obese, suggesting them to have a lower level of deprivation.

Physical activity participation expressed as time spent engaged in MVPA was negatively correlated with BMI SDS for the obese boys only, displaying a positive correlation with the obese girls. This is in contrast to all previous research which has demonstrated a protective effect of physical activity on body composition (221). However the chronically low levels of physical activity in all the obese girls, with some children failing to participate in any MVPA is likely to skew the results obtained. The lack of relationships seen for the lean children may be a result of the consistently high levels of physical activity seen which are probably not representative of the population as a whole. Lean participants were recruited through local health and fitness clubs and may have an interest and awareness in physical activity. Sedentary behaviours have been proposed to increase the risk of obesity though two distinct mechanisms, by promoting increased food consumption and replacing regular physical activity (40). In the present study, time spent sedentary correlated significantly with BMI SDS in the obese girls as previously observed in a group of similarly aged children (240).

There was no apparent age related decline in physical activity participation in contrast to previous research in young children (14). It may be that the older age of the participants in our study means that the decline has been missed or that the levels of MVPA were too low in the obese participants for this relationship to be observed. The Health Survey for England examines secular trends in physical activity participation and health behaviours, identifying that at all ages and stages of development; boys are more active than girls (3).

The obese boys' participation in physical activity was affected by BMI SDS and % BF whilst again there were no such relationships for girls or for lean boys. On average, girls performed almost half of the amount of the activity performed by boys, which probably explains the lack of relationships seen. When compared to current government guidelines of 60 minutes MVPA per day, this target was achieved or exceeded by 33% of the obese boys, 27% of the obese girls, 100% of the lean boys and 89% of the lean girls (47). A previous study of obese and lean adolescents in Sweden found patterns of participation differed by weight status with lean adolescents performing significantly more activity than obese (241). Further analysis revealed that BMI accounted for 20% of the total variance in PA counts suggesting obesity to act as a barrier to physical activity. The cross sectional nature of this and the present study however prevent any conclusions being drawn with regards the causality of this relationship; does obesity precede low physical activity or does obesity arise as a result of low physical activity?

4.6.7 Ethnic differences

It has previously been observed that people of South Asian origin experience significant health disparities with increased prevalence rates of obesity, CVD and type 2 diabetes apparent for both the adult and child populations (88;92;242). In addition ethnic differences in body composition and insulin resistance have been observed in lean, otherwise healthy adolescents (88).

Resting energy expenditure (REE) estimated using the Schofield equation was found to be reduced in girls of both ethnicities however there were no ethnic differences apparent for either estimated or measured REE. An earlier study examining ethnic differences in measured REE, found reduced REE in the SA adults however this difference was abolished when fat free mass (FFM) was taken into account (222). In the present study, the only ethnic difference in FFM was between South Asian girls who had significantly lower FFM than white males however there were no ethnic differences in measured REE.

Participation in physical activity was highest for the South Asian boys though small numbers may mean that the data are skewed by a couple of very active boys. There is a lack of studies utilising objective measurement techniques to assess physical activity differences between South Asians and the general population so until now, the majority of data was based upon self-report. The Health Survey for England found adult participation rates in MVPA to be highest for White

UK population, whilst the lowest rates were observed in the Bangladeshi population (14). Similar observations were made in children with Pakistani girls found to have the lowest participation rates in organised sport and activity (3). A literature review of suitable studies assessing ethnic differences concluded that on average there is a reduced participation in regular activity by the SA population when compared to the general population (243). Two further studies of SA and white adolescents have found self-reported levels of activity and active travel to be reduced in the SAs. A recent study of over 2000 primary school children, made objective assessments of physical activity and examined differences between children of white European, South Asian, and black African-Caribbean origin (99). Physical activity participation was consistently lowest for the SA children when expressed as activity counts, counts per minute, steps and time spent in moderate intensity activity. Fewer SA children achieved the Government guideline level of 60 minutes moderate intensity physical activity also reflecting the longer periods of time spent sedentary. Whilst SA boys were found to be more active in the current study, this is based upon 8 boys and therefore a larger number is needed to establish the true difference in representative populations. Dietary intake was lowest in the white girls however there were no significant between group differences and as previously discussed self-reported dietary intake is prone to underestimation in obese populations. Sedentary behaviours appear to be more influenced by gender than ethnicity with boys spending more time engaged in such behaviours than girls.

There was a striking difference in the relationship between body fat % and physical activity participation for the SA girls with increasing physical activity associated with increasing body fat%. This is the opposite of what would be expected and the reverse of the relationships observed for all of the male participants and for the white girls. Although this relationship is significant for SA females, they are the group who exhibited the lowest levels of physical activity and it may be that there is a threshold level of activity participation, below which no protective effect is noticed. Or it may be that activity levels were too low and numbers of participants too small for the expected relationship to be observed.

It is clear that the participants involved in this PhD project are different from their lean peers in terms of physical characteristics, metabolic health and also in lifestyle behaviours. The cross sectional nature of the study limits the ability to determine causality however some inferences can be made with regards the associations between lifestyle and body composition. The apparent gender and ethnic differences are consistent and warrant further investigation.

5 CHAPTER 5. ENERGY EXPENDITURE IN OBESE YOUNG PEOPLE PERFORMING DANCE MAT EXERCISE.

5.1 Abstract

Objective: To investigate whether the energy demands of dance mat exercise in lean, overweight and obese young people and obese children meets guidelines recommended by the UK Government and American College of Sports Medicine (ACSM) for improving and maintaining cardiovascular fitness.

Participants: 20 children aged 9-17 years old.

Procedure: Participants completed cycle ergometer test to exhaustion to determine HR_{PEAK} and VO_{PEAK}. Steady state energy expenditure, oxygen consumption (VO_2) and heart rate (HR) were assessed during the last 6 minutes of 10 minutes of continuous dance mat exercise.

Main outcome measure: Energy expenditure, % age predicted HR_{max} and $\%VO_{2RESERVE}$ during dance mat exercise.

Results: Mean ± standard deviation energy expenditure during dance mat exercise was similar to previously observed. The ACSM guideline levels for improving and maintaining cardiorespiratory fitness of 55% HR_{MAX} and 50% $VO_{2RESERVE}$ was exceeded in both groups with no between group differences.

Conclusions: Dance mat exercise evokes increases in energy expenditure, heart rate and $\%VO_{2RESERVE}$ sufficient to increase cardiorespiratory fitness in obese young people and children set by both the UK Government and the ACSM (55%HR_{peak} and 50% $VO_{2RESERVE}$). In obese, sedentary young people, dance mat exercise is sufficiently intense to contribute to daily exercise and therefore can be utilised to promote physical activity in this population.

5.2 Introduction

The rising prevalence of obesity in childhood and adolescence is having significant impact upon the physical and psychological health of young people with conditions such as type 2 diabetes and poor self-esteem becoming increasingly apparent (19;244). Numerous strategies to cope with this epidemic have been employed, for example the introduction of school meal nutrition guidelines and the publication of the UK Governments 'Healthy Weight, Healthy Lives' strategy in 2008 (209). However participation rates in regular physical activity remain low amongst children and adolescents (3). A common reason proposed to contribute to these low levels of activity amongst children and adolescents is that of increasing sedentary behaviours such as television viewing and video games. The Youth Risk Behaviour Survey in the USA identified that almost 25% of teenagers watched >4 hours TV a day with the risk of overweight increasing by 20-40% compared to teenagers who watched <1 hour/day (245). In addition, in the UK it has been reported that 100% of 6-10year olds and 97% of 11-15 years olds play an electronic game on a weekly basis indicating a high prevalence of sedentary behaviours amongst the young (161). Sedentary behaviours are thought to contribute towards the development of obesity through two main mechanisms; by promoting increased calorie consumption and replacing physical activity (34;37). The recent development of interactive multimedia games such as the Nintendo Wii and Dance Dance revolution (DDR) which increase the energy expenditure of the player may offer a solution to promoting physical activity in a predominantly sedentary population. Furthermore obese populations report many barriers to physical activity for example negative body image, and lack of access to facilities as well as an unwillingness to relinquish time spent in sedentary pursuits (159;160;165). Interactive computer games have the advantage of being performed within a person's own home and therefore remove many of the perceived barriers to exercise. The energy demands of the Nintendo Wii were evaluated in healthy children finding significant increases in energy expenditure (EE) over rest and 65kj/min/kg greater than when playing sedentary games (162). The exercise intensity was not deemed to be sufficient to contribute towards the recommended daily amounts of exercise for children though the recorded EE was likely to be an underestimation as the method used for measurement was predominantly focused on lower body movements whilst the Nintendo Wii principally involves upper body movement. The DDR concept involves either a home or arcade based dance mat connected to a computer screen onto which a series of moves are shown. The user has to match the moves on the screen with their feet on the mat and options include inputting your own music, and incorporating multi users. Previous research has evaluated the energy cost of the DDR in healthy, lean adolescents demonstrating significant increases in heart rate (HR) and ventilation (VO_2) above rest equivalent to moderate intensity exercise (>3 Metabolic equivalents) (165). Further studies have found the relative workload of DDR to be increased in overweight children compared to lean although there were no differences in energy expenditure adjusted for fat free mass (246), and increases in EE of 172% over rest in lean, healthy children. However a dissociation between VO_2 and HR was observed so that although HR reached American College of Sports Medicine Guidelines for improving and maintaining cardiorespiratory fitness of 55% HR_{MAX}, VO_2 failed to reach the guideline level of 50 % $VO_{2RESERVE}$. This observation has since been seen in other studies and has been attributed to the lack of upper body exercise involved, (165;246). When the DDR and the Wii were directly compared the energy demands of the DDR was higher in all children with boys consistently exercising at a higher intensity than girls (247). Furthermore in the same study, an acute reduction in large artery elasticity was demonstrated following DDR exercise though it is unclear for how long this change was maintained.

The worldwide sales of dance mats have topped 8 million and DDR is being increasingly used in schools and within the community to promote physical activity (157;167;248). In addition there have been several pilot studies to test the effectiveness of using dance mat exercise as a tool for promoting physical activity in children although technical difficulties and choice of population have limited the current success (167). However, as yet the energy demands of dance mat exercise have not been established in obese children and young people, the population who would perhaps most benefit from this type of activity.

We therefore measured the energy demands of dance mat exercise in obese young people and children with the aim to investigate whether the intensity meets the UK Government guidelines of >3MET and the ACSM guidelines for improving fitness of 55%HR_{PEAK} and 50%$VO_{2RESERVE}$ (249).

5.3 Aims

The aims of this chapter are to establish the energy demands of continuous dance mat exercise in obese children. Heart rate and ventilation responses to continuous dance mat exercise will be compared to responses achieved during maximal effort and compared to American College of Sports Medicine (ACSM) guidelines for improving and maintaining fitness.

It is expected that continuous dance mat exercise will be sufficiently intense for obese children to achieve ACSM guidelines for improving and maintaining cardiorespiratory fitness.

5.4 Method

5.4.1 Participants and settings

Young males: 20 obese children and young people aged 9-17 years were recruited through the endocrine clinic at the Birmingham Children's Hospital. Children who had a BMI that exceeded the 95th percentile for age and gender were invited to participate. Exclusion criteria included the refusal of the child and/or parent/guardian to provide informed consent and the presence of comorbidities that could prevent participants from exercise. The Black Country LREC ethics board approved all procedures.

5.4.2 Anthropometry

Body mass was recorded to the nearest 0.1kg and height recorded to the nearest 0.1cm using calibrated scales (Ohaus Champ II, USA) and a wall mounted stadiometer (Seca, Germany). Body mass Index (BMI) was calculated in kg/m^2. Body fat % in the children was obtained using a Tanita Bioimpedance body fat analyser 410GS (Tanita UK, Middlesex, UK).

5.4.3 Laboratory assessments

All laboratory assessments were performed with participants having fasted for 2 hours.

5.4.3.1 All out progressive exercise

Obese children performed a progressive cycle test to exhaustion using the McMaster protocol which bases the workload upon the height and the gender of the child. For all participants cycling rate was maintained at 50 rpm whilst the workload increased every 2 minutes until exhaustion. In both tests, participants were encouraged to continue until volitional exhaustion unless the participant experienced dizziness, nausea or an excessive rise in HR> 200bpm in which case the test was terminated. HR was continuously measured (Polar Vantage NV, Finland), with the peak value recorded. Expired air samples were continuously measured using an online indirect calorimetry system (Oxycon Pro, Cardinal Health UK) calibrated using gases of known concentration. A mouthpiece and nose clip were worn for the duration of the test to obtain continuous breath by breath measurement of VO_2, VCO_2 and RER which were then averaged every minute. $VO_{2RESERVE}$ was calculated as VO_{2PEAK} – VO_{2REST}, with VO_{2REST} measured from chapter 4.

5.4.3.2 Familiarisation

All participants practiced on the home version of Dance Factory (Codemasters, UK) for up to one hour, until sufficiently competent to complete three consecutive songs in medium difficulty. A Sony Playstation 2© was used alongside the Dance Factory game which features a game pad (107cm x 88cm) on which the player stands in front of a projection screen. During the game a series of 'moves' or instructions are displayed on the screen which the players try and match with their feet on the relevant arrows of the game pad. Steps correspond with the rhythm of the music and the Dance Factory game allows for users to input their own music into the programme for which 'dances' will be created. Familiarisation began with a brief instruction from the researcher after which participants were able to select their own music.

5.4.3.3 Assessment of energy expenditure

No more than a week following familiarisation, participants returned to the lab having refrained from the consumption of food or drink other than water for the previous 2 hours and participation in vigorous activity for the previous 12 hours. All participants performed three consecutive dances in endurance mode with level of difficulty set to medium. All participants performed the same three dances in a consecutive fashion with a maximum of 10 seconds between songs. Expired air samples were continuously recorded using an online indirect calorimetry system (Oxycon pro, Cardinal Health, UK). HR was continuously recorded and averaged across every minute. VO_2 was expressed as $\%VO_{2RESERVE}$, and HR calculated as

$\%HR_{MAX}$. VO_2 was converted into Metabolic equivalents (MET) with one MET, the energy expenditure of rest assumed (190). Due to the time taken to reach steady state exercise, the first four minutes of exercise were discarded with the remaining six minutes averaged. The procedure was kept consistent for all participants.

5.4.4 Statistical analysis

Physiological responses to the progressive treadmill test were obtained with respect to VO_{2PEAK} expressed in absolute and relative terms, HR_{PEAK} and $VO_{2RESERVE}$, calculated as $VO_{2PEAK} - VO_{2REST}$ with VO_2 rest assumed to be 3.5ml/min/kg. Due to a limited number of participants reaching maximal exertion, predicted maximal heart rate (HR_{MAX}) was used for determining the percentage of HR workload reached. The Tanaka equation was used to calculated age predicted maximal heart rate (220-age) (250). Ventilation data obtained during the dance mat protocol was averaged across the final two minutes and used to estimate EE, expressed in absolute and relative terms. Between gender differences were examined using paired t-tests. Statistical significance was set at $P<0.05$ level and SPSS version 15 was used for analysis. All data are expressed as means ± standard deviation.

5.5 *Results*

5.5.1 Obese children

Participant characteristics and cardiorespiratory responses to maximal cycle exercise for the obese boys and girls are summarised in table 5.1.

Group	Obese boys n=8	Obese girls n=12
Age (yrs)	12.6 ± 1.85	13.7 ±0.100
Height (m)	1.64 ± 0.100	1.61 ± 0.730
Weight (kg)	80.0 ± 20.6	93.5 ± 19.6
BMI (kg/m^2)	29.3 ± 5.63	35.6 ± 6.48*
BMI SDS	2.67 ± 0.610	3.09 ± 0.750*
Body fat %	38.4 ± 8.15	44.6 ± 5.91*
Fat free mass (kg)	48.2 ± 9.04	51.1 ± 8.00
REE (ml/min/kg)	2.91 ± 0.60	2.56 ± 0.52
Maximal exercise characteristics		
VO_{2PEAK} (ml/min/kg)	26.1 ± 9.01	20.5 ± 4.84*
VO_{2PEAK} (l/min)	1.97 ± 0.40	1.86 ± 0.36
HR_{MAX} (bpm)	207.4 ± 1.85	206 ± 2.10

Table 5-1. Participant characteristics and cardiorespiratory responses to treadmill exercise in obese boys and girls.
** P<0.05. BMI SDS – body mass index standard deviation score*

The boys and girls were similar in terms of age, and height however there was a tendency for the girls to be heavier, and girls had a significantly higher mean BMI (P<0.05). Girls had a higher percentage of body fat, and attained a lower value of peak oxygen uptake. To further compare, BMI standard deviation scores were calculated using 1990 reference values (47). Obese girls were significantly more obese compared to the boys. Cardiorespiratory responses to dance mat exercise in obese children are summarised in table 5.2.

Group	Obese boys n=8	Obese girls n=12
VO_2 (ml/min/kg)	13.0 ± 2.94	10.7 ± 2.69
% VO_{2MAX}	51.5 ± 15.2	49.2 ± 10.1
% $VO_{2RESERVE}$	61.5 ± 20.8	61.6 ± 16.49
HR (bpm)	125.4 ± 15.5	137 ± 10.0
% HR_{MAX}	61.5 ± 8.50	66.6 ± 4.84
EE (kj/min)	20.2 ± 3.97	20.2 ± 5.26
EE (kj/min/kg)	0.26 ± 0.06	0.22 ± 0.05
MET	4.60 ± 1.06	4.25± 1.12

Table 5-2. HR, VO2 and EE responses to dance mat exercise.

Obese boys and girls increased their VO_2, HR and EE in response to 10 minutes of continuous dance mat exercise with no gender differences apparent. The ACSM guideline levels for improving and maintaining fitness of 50% $VO_{2RESERVE}$ and 55% HR_{MAX} were comfortably exceeded by both genders. The MET scores were once again indicative of moderate intensity exercise with no differences between genders. The relative workloads of obese boys and girls performing 10 minutes of continuous dance mat exercise are summarised in figure 5.1.

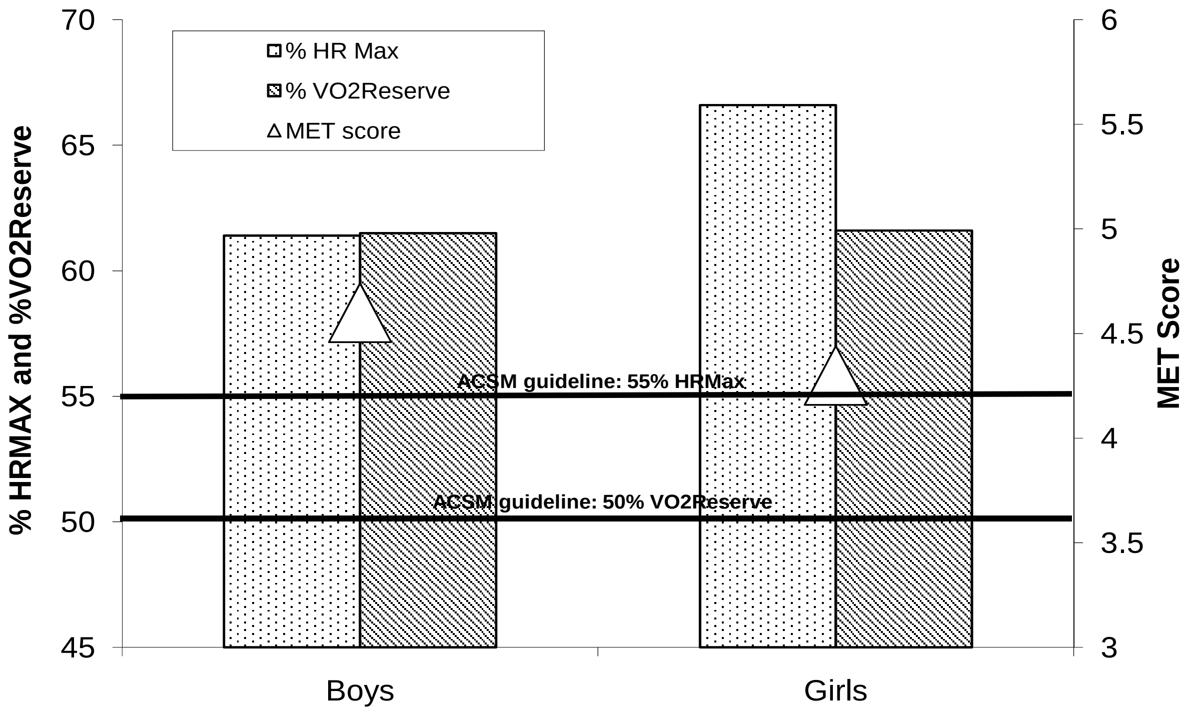


Figure 5-1. Relative workloads of obese boys and girls during 10 minutes of continuous dance mat exercise.

5.6 Discussion

The major finding of the current study is that 10 minutes of continuous dance mat exercise elicited increases in HR, VO_2 and EE above rest with no differences in the level of % HR_{MAX} and % $VO_{2RESERVE}$ reached between obese boys and girls. All groups exceeded the ACSM guideline level for improving cardiorespiratory fitness of 55% HR_{MAX} and the ACSM guideline level for improving cardiorespiratory fitness of 50% $VO_{2RESERVE}$ was exceeded. Previous studies have consistently demonstrated dissociation between the VO_2 and HR responses to dance mat exercise with HR reaching a higher relative level than VO_2. This was not observed for the obese children in the current study. The current study is the first to include obese participants and it may be that the greater body mass and hence energy demand required to perform the body movements involved explains the higher VO_2 response observed. VO_2 is expressed as a function of $VO_{2RESERVE}$ calculated as the difference between VO_{2MAX} and VO_{2REST}. Maximal effort was not achieved by all of the participants in this study and therefore the peak value, VO_{2PEAK} achieved was used for comparison. It may be that the observed reductions in VO_{2PEAK} were a reflection of poorer fitness, or it may be that the effort exerted by the obese participants during the maximal exercise tests was less and hence the VO_{2PEAK} values obtained were an underestimation.

The girls expended less energy than the boys and although this difference was not significant, the potential gender difference is one that is worth exploring. Previous research has shown that gender is a predictor of resting energy expenditure with girls exhibiting lower REE than boys and this may also be true for physical activity energy expenditure (PAEE) (251).

When compared to prior studies, the rates of EE observed in the children are similar, if not slightly higher than previously observed. As there were no differences between genders, average EE was equated as 4.83kcal/minute, similar to the 4.60±1.30kcal/minute observed previously in overweight children and greater than the 2.90±0.70kcal/min observed in non overweight children (246). The values observed were also greater than the average EE of 3kcal/min observed for Wii boxing and DDR in previous studies (164;247). The current UK Government guidelines for physical activity in children suggest that all children should participate in at least 60 minutes of moderate intensity activity every day. If the obese children in the current study participated in dance mat exercise for 60 minutes every day, this would lead to an energy expenditure of 290kcal per day. It has been suggested than an energy deficit of 3500kcal is required to lose 1lb of body weight in adults (219). If this is also true for obese children, and the children continued to perform dance mat exercise for 60 minutes everyday whilst maintaining diet, the children could potentially lose up to 30lb or 13.7kg of body weight in a year. Whilst it is unlikely that children would perform dance mat exercise for 60 minutes a day, a kcal deficit of 100kcal can be achieved within 21minutes. An energy deficit of 100kcal/day has been suggested to prevent weight gain in 90% of the US population, something which could be achieved in approximately 15 minutes for the lean adults, and 11 minutes for the overweight and obese adults. For all groups, exercise intensity was deemed to be ‘moderate’ using the definition of Metabolic equivalents (MET) (190). One MET is assumed to be the energy expenditure of rest (3.5ml/min/kg) with the intensity of other activities assessed by how much they exceed rest or 1MET. The minimum MET score for moderate intensity activity is 3METs exceeded by all groups with most groups approaching the definition of vigorous intensity activity, 6 METs.

In conclusion, dance mat exercise is suitably intense in obese children to exceed the recommendation for moderate intensity physical activity. The observed EE was similar to that seen in previous studies although the greater body mass of the obese participants meant that in absolute terms they tended to have a higher EE than previously seen for both DDR and the other popular interactive media game the Nintendo Wii. This study is the first to demonstrate that in clinically obese children and adolescents, dance mat exercise is sufficiently intense to contribute towards daily recommended levels of activity and therefore should be promoted in this population. Clinically obese children and adolescents are characterised by chronically low levels of fitness and poor self-esteem and therefore there is a great need for suitable modes of exercise which can promote weight loss and increase physical activity.

6 CHAPTER 6. THE EFFECTIVENESS OF A 12 WEEK, HOME BASED DANCE MAT EXERCISE INTERVENTION IN OBESE CHILDREN AND YOUNG PEOPLE.

6.1 Abstract

Objective: To determine the effectiveness of a 12 week home based exercise intervention using playstation dance mats.

Participants: 34 obese children and young people (male = 17) aged 9-18 years (average: 13.5 ± 1.99 years) with BMI > 95th centile.

Procedure: All children were asked to complete a 12 week, home based exercise intervention using playstation dance mats. The exercise prescription was to perform dance mat exercise on at least 4 days of the week for at least 20 minutes at a time. Measurements were performed at baseline and after 6 and 12 weeks.

Main outcome measures: Body composition, cardiovascular fitness and objectively measured physical activity.

Results: 28 children completed the intervention. BMI SDS was significantly reduced by -0.11±0.14 and -0.07±0.10 for the boys and girls respectively. Body fat reduced by an average 2.53±2.46% for the boys and 1.26±2.25% for the girls. Cardiorespiratory fitness was significantly improved for both groups; by 15% in the boys and 17.8 % in the girls accompanied by significant reductions in heart rate at submaximal exercise intensities. These changes all point towards an improved quality of life in the obese children and young people.

Conclusions: The most significant benefits of a 12 week dance mat intervention in obese children and young people were reductions in BMI SDS and body fat % and improvements in physical fitness. In addition, lifestyle physical activity increased to such an extent that on average the participants exceeded Government guidelines for MVPA participation. Adherence was higher for girls than boys suggesting dance mat exercise to be a preferable activity for girls.

6.2 Introduction

The recent epidemic of obesity in children and young people has been accompanied by increasing reports of impairments in physical health and psychological well-being in those affected (127;130). Furthermore there is substantial evidence for the tracking of obesity and associated co-morbidities into adulthood (20). At age 3-5 years, obese children have a less than 40% chance of remaining obese as an adult; this risk increases to over 60% by age 12 for girls and age 17 for boys (20). Therefore much emphasis has been placed on the development of interventions aimed at the treatment and prevention of obesity in the young with a focus on the restoration of energy balance and maintenance of healthy weight in this critical period of the lifespan. Prevention interventions frequently take place in a community or school setting and often take a multi-component approach to healthy lifestyle and behaviour encouraging energy balance through the adoption of appropriate energy intake and expenditure levels. Interventions developed to treat obesity in childhood are primarily aimed at restoring energy balance through promoting physical activity, reducing dietary intake or via a combination of the two. Purely dietary interventions are traditionally ineffective in the long term (147) and therefore multi-disciplinary or exercise alone interventions are more commonly utilised. In extreme cases of childhood obesity, pharmacological agents such as metformin and sibutramine are increasingly used (171), with bariatric surgery also available as an option in cases of extreme obesity (173). Community intervention programmes such as MEND and WATCH-IT are also gaining popularity as they provide social support for the child and offer education for the whole family, thus encouraging long term behaviour change (155;252).

The benefits of exercise are far reaching and can occur independently of changes in body weight and composition. For example improvements in insulin sensitivity, reduced abdominal adiposity and improved arterial elasticity have all been observed in obese children and adults as a direct result of increased physical activity and exercise (148;253) independently of changes in body weight. However adherence to traditional exercise interventions is low in obese children and adolescents with attrition rates of up to 30% reported at 6 months (158). It is suggested that poor adherence may be related to the numerous real and perceived barriers to exercise frequently experienced by obese populations. The most common of these include body image awareness, lack of access to facilities and social stigmatisation; therefore interventions need to address these barriers and provide an environment in which the obese child feels confident and motivated to perform the required exercise (159). A further barrier to exercise is the length of time children and young people spend engaged in sedentary activities such as television viewing or personal computer use. It has been reported that as many as 100% of 6-10 year olds and 97% of 11-15 year olds in the UK play some form of electronic game at least once a week (161). Furthermore in the USA, over 25% of children reported watching more than 4 hours of television every day, with graded relationships apparent between hours spent watching TV and BMI for both genders and across all ages (32). A survey in the USA revealed that whilst children and young people are often aware of the health benefits of regular physical activity they are not prepared to give up time spent in sedentary pursuits. Therefore the recent development of interactive computer games which increase the energy expenditure of the player may offer a solution; in effect time spent in sedentary activity becomes active. There are a few examples of interactive games, with the umbrella term ‘exergaming’ used to describe all new generation active computer and video games such as the Nintendo Wii, the Sony Eye-toy and the Dance Dance revolution concept which could contribute to young people’s daily energy expenditure.

Currently, the UK Government recommends that every child achieves 60 minutes of participation in moderate to vigorous physical activity (MVPA) each day of the week whilst for adults the recommendation is for 30 minutes MVPA at least five times a week (224). Increasing emphasis is being placed on the accumulation of lifestyle activities such as walking and stair climbing to achieve these targets, with suggestions that exergaming could be used to contribute to daily activity. Exergaming may also be a useful exercise tool in obese children and adolescents who experience many barriers to exercise. Active video and computer games can be utilised within a person's home thus eliminating many of the potential barriers to exercise such as a lack of access to facilities and negative image awareness.

Before exergaming can be promoted as a useful exercise tool, it is important that the energy demands are adequately and accurately assessed, and that the relative intensity of the exercise is compared to other activities. The most popular active video games to date are the Nintendo Wii, the Sony Eye Toy and the Dance Dance Revolution concept (DDR). The Nintendo Wii is a handheld device which encourages the player to make an appropriate action which is reciprocated on the screen. The Sony Eye toy is a digital camera device worn by the user which allows for interaction with games using motion and finally the DDR concept involves the use of a dance mat connected to either an arcade game or home computer. On the screen, a series of 'moves' is shown which the user is required to match by touching the appropriate arrow on the mat.

A range of studies have previously assessed the energy demands of exergaming activities in adults and children with dance mat games most commonly assessed. The energy expenditure of Wii sports was found to be 30kJ/kg/min in adolescents, failing to meet the threshold of moderate intensity activity (162). Nintendo Wii activity is also characterised by predominantly upper body movement. The Sony Eye toy has also been evaluated in 8-12 year old children finding increases in energy expenditure of 108% compared to rest (164). The majority of studies have assessed the energy demands of dance mat exercise with the predominant conclusion being that dance mat exercise is of moderate intensity (164;165;247;254). However when compared to ACSM guidelines for improving and maintaining fitness, there appears to be a consistent dissociation between heart rate (HR) and VO_2 responses. Whilst HR seems to consistently exceed the recommended threshold of 55% HR_{MAX}, VO_2 often fails to reach the threshold level of 50% $VO_{2RESERVE}$, maybe as a result of the lack of upper body movement.

The population who are most suitable for these kinds of active video games are overweight, obese and sedentary children and young people who have low levels of physical activity. An unpublished study compared the energy demands of 10 minutes continuous dance mat exercise with measured maximal values in lean, overweight and obese young adults and obese children (255). In all groups, dance mat activity was moderately intense, though ACSM guidelines for improving fitness were only exceeded by the obese adults and children.

It would seem that dance mat activity is suitably intense for obese children and young people to reach government recommended levels of moderate intensity activity, and can be promoted as an exercise tool in interventions to increase physical activity. A pilot study in obese 9-18 year olds provided all participants with a DDR and asked them to perform exercise on 5 days of the week for 30 minutes at a time (166). Adherence was recorded through a diary and a video memory card and biweekly phone calls were conducted to maintain dance mat use.

Despite these efforts, only 40% of the children performed dance mat exercise at least twice a week by 3 months, reducing to 9% at month 6. Potentially as a consequence of the low adherence, regression models adjusted for baseline BMI SDS failed to find a significant decrease in BMI. Further studies have also demonstrated poor adherence to exercise prescriptions when dance mats were employed (167). The majority of children were lean at baseline and therefore as expected there were no changes in BMI Z score across the intervention. Focus groups with both the participants and their parents did identify general satisfaction and enjoyment with the DDR game, with more than half of the parents believing that DDR did ultimately increase their child's PA and that they would recommend the game to others. Further pilot studies in children using active games such as the DDR have also reported increases in physical activity, reductions in sedentary behaviours, slight reductions in body weight, and improvements in cardiovascular parameters such as flow mediated dilation (167;168). However studies so far have predominantly involved lean or overweight children who have relatively high levels of physical activity at baseline. The crucial open question is whether significant improvements will be observed in obese and sedentary children.

6.3 Aims and hypothesis

The aim of this study was to assess the feasibility and acceptability of a 12 week home based intervention using Playstation Dance mats in obese children and young people. A number of baseline and follow up measures were taken, to evaluate the effectiveness of the intervention. The primary aims of this study were:

- To establish the adherence of obese children and adolescents to a home based exercise intervention.
- To examine the changes in a number of primary and secondary outcomes such as body weight and composition, physical fitness, physical activity and metabolic health.
- To estimate the effect size of the intervention on anthropometric and physical exercise parameters.

6.4 Methods

6.4.1 General design

This study took the form of a prospective observational study to test the feasibility and efficacy of a 12 week intervention using playstation dance mats in obese children and young people.

6.4.2 Recruitment

Recruitment for the obese participants took place in the General Paediatric and Endocrine clinics at the Birmingham Children's Hospital (BCH). All children aged 9-18 years old who fulfilled the inclusion criteria (BMI SDS >95th percentile for age and gender) were informed of the study aims and objectives and invited to participate. Interested children and their families were provided with full study information and a week later, a screening telephone call was made. An appointment was then made for the child and their parent to attend the BCH for completion of informed consent.

6.4.3 Inclusion/exclusion criteria

All children who had a BMI SDS that exceeded the 95th percentile for age and gender were eligible for the present study. Exclusion criteria was a refusal of the child and/or their parent to provide informed consent, the presence of learning difficulties and the presence of any medical condition that would prevent the child from exercising (e.g. severe asthma). As this was a pilot study, the eligibility criteria were designed to be liberal. All participants were required to provide informed consent prior to participation and all procedures were approved by the Black Country Research Ethics Committee.

6.4.4 Intervention

All obese children were invited to participate in a 12 week, home based exercise intervention using playstation dance mats, with follow up appointments scheduled for 6 and 12 weeks. All children were provided with a Dance Factory (Codemasters, UK) game for the Playstation 2, a dance factory dance mat and where necessary a playstation 2 (Sony, UK). The Dance Factory game and dance mat were demonstrated to all participants with instructions including how to upload music and which modes the dance mat game could be played in. An instruction manual was provided to all participants alongside a telephone number to contact in case of technical difficulties. The children were asked to perform the dance mat exercise on four days of the week for 20 minutes at a time. This prescription was selected as it seemed attainable and based upon the baseline levels of moderate to vigorous physical activity (MVPA) would increase physical activity participation to recommended levels (47). Children were asked to complete a weekly diary to record adherence to the dance mat exercise and also participation in other activities. The principle researcher made weekly telephone calls and emails to all participants to track progress and adherence.

6.4.5 Assessments

6.4.5.1 Anthropometry and body composition

Height and weight were recorded to the nearest 0.1cm and 0.1kg respectively on calibrated scales and used to calculate body mass index (BMI). Standard UK growth charts were used to calculate age and gender appropriate BMI SDS scores for each child (182). A Tanita 410GS body fat analyser (Tanita, UK) was used to measure body composition expressed as body fat %, fat mass (FM) and fat free mass (FFM). Waist circumference was obtained at the midpoint between the lowest rib and the iliac crest using a non elastic flexible tape measure. Two measurements were taken and averaged to the nearest millimetre.

6.4.5.2 Physical activity and sedentary behaviour

PA was objectively assessed using an Actiheart (AHR) combined accelerometry and heart rate monitor (CamNtech, Cambridge, UK). The AHR is worn on ECG pads strapped to the chest and records acceleration and heart rate in 1 minute epochs for up to 11 days and is a valid measure of PA and energy expenditure in children and adults (185;256). Participants were asked to wear the AHR at all times for 5 days including during sleep, at baseline, 6 and 12 weeks. AHR data was exported into an excel file and analysed using a pre-written MACRO. The data was summed as daily activity counts, average activity counts per minute, physical activity energy expenditure (PAEE), total energy expenditure (REE + PAEE), and time spent in moderate to vigorous physical activity (MVPA). MVPA was calculated by converting PAEE into a MET score by dividing by REE. Anything less than 3METS was deemed to be light intensity, 3-5.9METs is moderate intensity and >6METs is vigorous. Therefore MVPA was calculated from the sum of moderate and vigorous activity. Self-report time spent engaged in TV viewing or personal computer use on weekdays and weekends was recorded at baseline, 6 and 12 weeks.

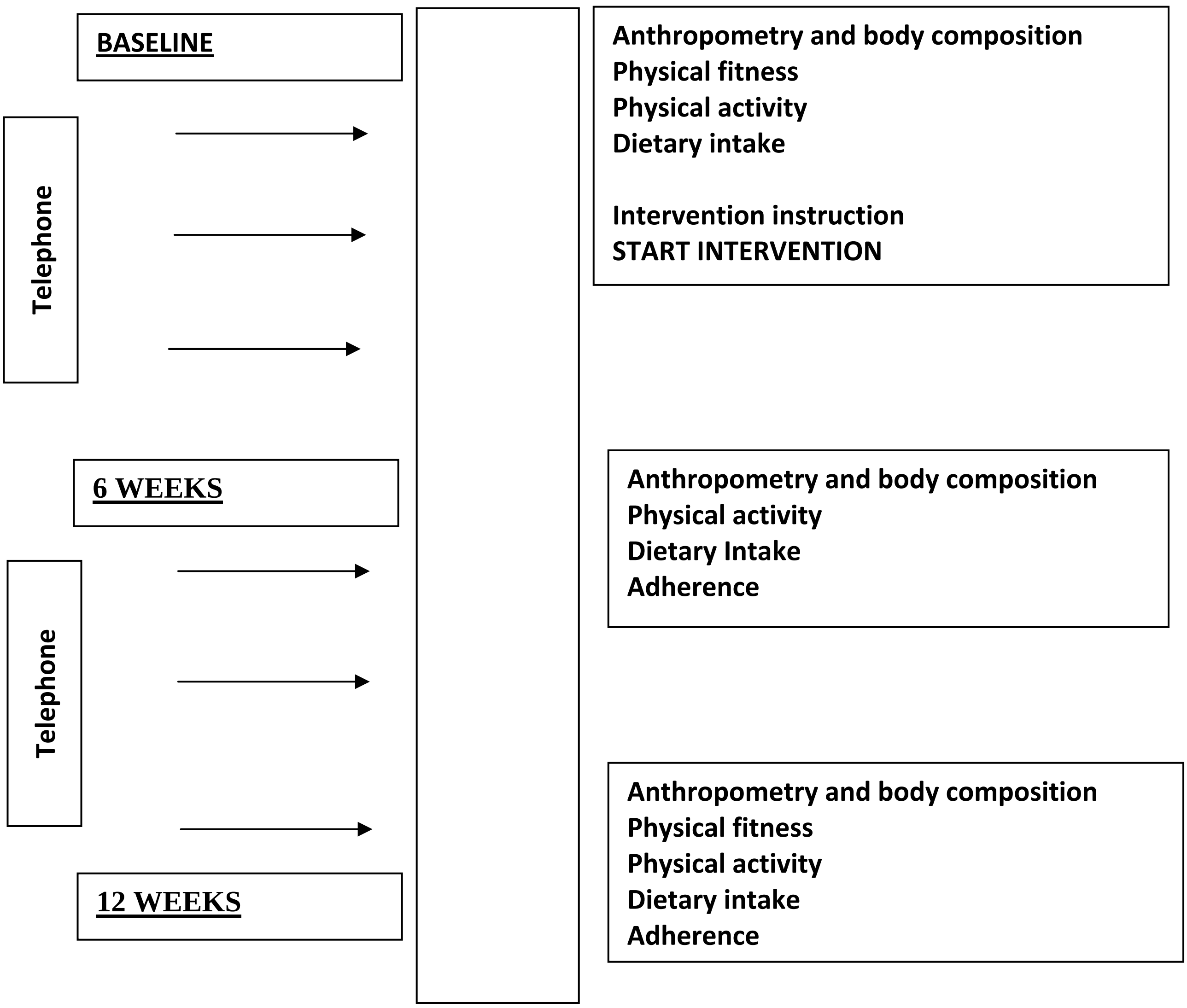
6.4.5.3 Physical fitness

Cardiovascular fitness was assessed using the McMaster cycle test to volitional exhaustion. This test requires the participant to maintain a cycling rate of 50rpm throughout the test with initial workload and work load increments decided by the age, gender and height of the child (193). Participants were asked to exercise until volitional exhaustion with encouragement provided. Heart rate (HR) was continuously measured using a radiotelemetry HR monitor, (Polar Vantage NV, Kempele, Finland) and indirect calorimetry was used to obtain breath by breath measures of VO_2, VCO_2 and RER. Peak VO_2 and HR were recorded and used as outcome measures. HR at the given workloads of 50W and 100W were also recorded as a measure of cardiovascular fitness.

6.4.5.4 Dietary Intake

Dietary intake was assessed at baseline, 6 and 12 weeks using two methods in an attempt to improve accuracy. Participants were asked to complete a 24hour recall with the help of the principle investigator. A three day food diary was also provided and the children and families were instructed to complete the diary on at least one weekend day and to include as much information as possible.

6.4.6 Timeline of participation



6.4.7 Statistical analysis

All data was checked for normality using the Shapiro-Wilk test with significance set at $P<0.05$. Any data that was not normally distributed was transformed using log to base 10. Baseline differences between genders were analysed using a paired samples t-test with significance set as $P<0.05$. Repeated measures ANOVA were used to determine the effect of gender and time through the intervention, and only the children who completed the intervention were included. Significant results were examined using paired sample t-tests and a Bonferroni correction ($P< 0.017$).

6.5 Results

6.5.1 Baseline Data

A total of 34 participants (17 boys, 17 girls, aged 13.5 ± 1.99 years) provided consent to participate in the intervention. According to 1990 British growth reference data, all participants exceeded the definition for obesity, BMI> 95th centile (182), with 23% of the participants exceeding a BMI SDS >3.5, equivalent to morbid obesity or an adult BMI of 40kg/m^2. A total of 56% (n=19) of participants were of white ethnicity, 32% (n=11) were South Asian ethnicity and 12% (n= 4) were of black ethnicity. Baseline characteristics are summarised in table 6.1.

Table 6-1. Baseline characteristics.

	Males (n=17)	Females (n=17)	Significance
Age (yrs)	13.7 ± 1.92	13.9 ± 2.03	0.233
Rank	20.5 ± 20.6	29.7 ± 29.5	0.298
Height (m)	1.66 ± 0.18	1.63 ± 0.07	0.273
Weight (kg)	85.8 ± 22.1	95.4 ± 20.4	0.197
BMI SDS	2.82 ± 0.52	3.21 ± 0.67	0.063
Body fat %	37.0 ± 7.15	43.5 ± 6.58	0.009**
Fat free mass (kg)	53.1 ± 11.8	52.4 ± 8.43	0.849
Fat mass (kg)	32.7 ± 13.0	42.1 ± 14.0	0.050*
Waist circumference (cm)	99.4 ± 13.6	106 ± 18.7	0.232
Resting heart rate (bom)	74.8 ± 7.19	79.5 ± 11.7	0.168

**P<0.05, **P<0.01 Significant differences between genders*

There were no baseline differences between genders for age, height, weight and BMI SDS. Girls displayed a significantly increased body fat % and fat mass (FM) compared to the boys. Average activity counts per minute were significantly increased in the boys compared to girls (50.1±23.9 vs 33.3 ± 10.5, P=0.012), as was time spent in moderate intensity physical activity (MVPA). On average the boys spent almost twice the amount of time as the girls engaged in MVPA (69.1±52.6 mins vs 38.5 ± 26.0 mins, P=0.039) with 41% of the boys and 24% of the girls attaining guideline levels of MVPA participation (47). However boys also spent more time engaged in sedentary behaviours achieving on average over 5 hours a day of TV viewing or computer use compared to 4.5 hours for the girls (P=0.072)

6.5.2 Adherence

In all, 6 children (17.6%) failed to complete the intervention and did not provide 12 week measurements. Of these five were boys suggesting the intervention to be more appealing for female participants. Adherence to the exercise sessions was measured through self-report records and through the use of the Actiheart monitor at 6 and 12 weeks. Using the self- report measure 13 (46%) of the children failed to complete the prescribed amount of 20 minutes four times a week exercise. However at 6 weeks, the AHR data indicated that only one child had failed to accumulate an average MVPA of 20/mins per day or more. By 12 weeks, 79% of the children were achieving the government guideline level of >60mins MVPA per day as measured by AHR data.

6.5.3 Primary outcome measures

For both genders there were small but significant increases in height across the 12 week intervention (table 6.2). On average the boys lost 0.14kg in weight whilst the girls did not change. BMI SDS decreased significantly in both groups as did body fat %, and fat mass. The average BMI SDS changes of -0.11 ± 0.14 and -0.07 ± 0.10 for the boys and girls respectively were higher than that observed in the community Watch-IT obesity treatment scheme (-0.07) after 6 months (252). Waist circumference decreased in both groups by over 2cm showing a main effect of time and on average WC still exceeded the 95th percentile for age and gender suggesting that abdominal adiposity remained a risk factor in these children (10). Despite no real changes in body weight, there were significant reductions in fat mass for both groups, accompanied by increases in fat free mass. Fat free mass is the predominant contributor to resting energy expenditure (REE) and therefore it can be predicted that REE would have increased following the intervention. Both groups achieved a fat mass loss of over 1 kg.

Outcome	Mean ± SD		F Statistic	
	Boys (n=12)	**Girls (n=16)**	**Time effect**	**Group-time effect**
Height (m)			56.5 (P=0.00)	8.41 (P=0.01)
Baseline	1.66 ± 0.18	1.62 ± 0.06		
12weeks	1.68 ± 0.09**	1.63 ± 0.06**		
Change	0.018 ± 0.01	0.0081 ± 0.001		
Weight (kg)			0.019 (P=0.89)	0.032 (P=0.86)
Baseline	84.0 ± 19.3	93.4 ± 19.3		
12 weeks	83.8 ±1 8.3	93.4 ± 19.2		
Change	-0.14 ± 2.80	0.002 ± 1.99		
BMI SDS			17.9 (p=0.00)	0.900 (P=0.35)
Baseline	2.74 ± 0.53	3.18 ± 0.63		
12weeks	2.63 ± 0.52*	3.10 ± 0.69**		
Change	-0.11 ± 0.14	-0.07 ± 0.10		
Body fat %			18.0 (P=0.00)	2.02 (P=0.17)
Baseline	36.5 ± 7.19	43.1 ± 41.8[a]		
12 weeks	33.9 ± 5.75**	41.8 ± 6.8*[a]		
Change	-2.53 ± 2.46	-1.26 ± 2.25		
Fat free mass (kg)			18.6 (P=0.00)	0.39 (P=0.54)
Baseline	53.1 ± 11.8	51.9 ± 8.36		
12 weeks	54.8 ± 10.6**	53.5 ± 8.40*		
Change	2.16 ± 2.17	1.61 ± 2.37		
Fat mass (kg)			12.2 (P=0.00)	1.31 (P=0.26)
Baseline	31.2 ± 10.9	40.8 ± 13.3[a]		
12 weeks	29.0 ± 9.24*	39.7 ± 13.6*[a]		
Change	-2.18 ± 2.97	-1.11 ± 2.02		
Waist circumference (cm)			7.08 (P=0.01)	0.30 (P=0.87)
Baseline	98.8 ± 14.6	104 ± 17.4		
12 weeks	96.3 ± 12.9	102.1 ± 14.6		
Change	-2.52 ± 4.70	-2.22 ± 4.64		
RHR (bpm)			2.12(P=0.16)	0.016 (P=0.90)
Baseline	73.8 ± 5.29	78.9 ± 11.8		
12 weeks	72.3 ± 4.62	77.7 ± 9.02		
Change	-1.42 ± 2.54	-1.19 ± 5.78		
VO_{2PEAK} (ml/min/kg)			94.4 (P=0.00)	0.067 (P=0.80)
Baseline	26.6 ± 6.34	19.0 ± 5.52[a]		
12 weeks	30.4 ± 6.89**	22.6 ± 5.52**[a]		
Change	3.76 ± 1.52	3.57 ± 4.56		
VO_{2PEAK} (ml/min/kgFFM)			33.8 (P=0.00)	0.381 (P=0.54)
Baseline	41.5 ± 6.61	33.8 ± 9.41		
12weeks	45.8 ± 7.47**	39.1 ± 6.95**		
Change	4.30 ± 3.22	5.32 ± 4.99		
HR_{MAX}			1.13 (P=0.30)	0.050 (P=0.83)
Baseline	182 ± 11.9	175 ± 15.9		
12weeks	184 ± 9.20	178.4 ± 13.0		
Change	2.04 ± 11.3	3.13 ± 13.8		

Table 6-2. Changes in body composition in response to the 12 week intervention.
*RHR: Resting heart rate. * P<0.05 within gender differences across time, **P<0.01 within gender differences across time. a –P<0.05, between gender difference.*

Cardiorespiratory fitness was also considered to be a primary outcome measure and significantly improved across the 12 week intervention. VO_{2MAX} was not achieved by all participants and so the peak value (VO_{2PEAK}) achieved was taken as the outcome measure. VO_{2PEAK} improved by 15.0% in the boys and 17.8% in the girls. Submaximal HR responses to exercise at 50W and 100W are displayed below (figure 6.1).

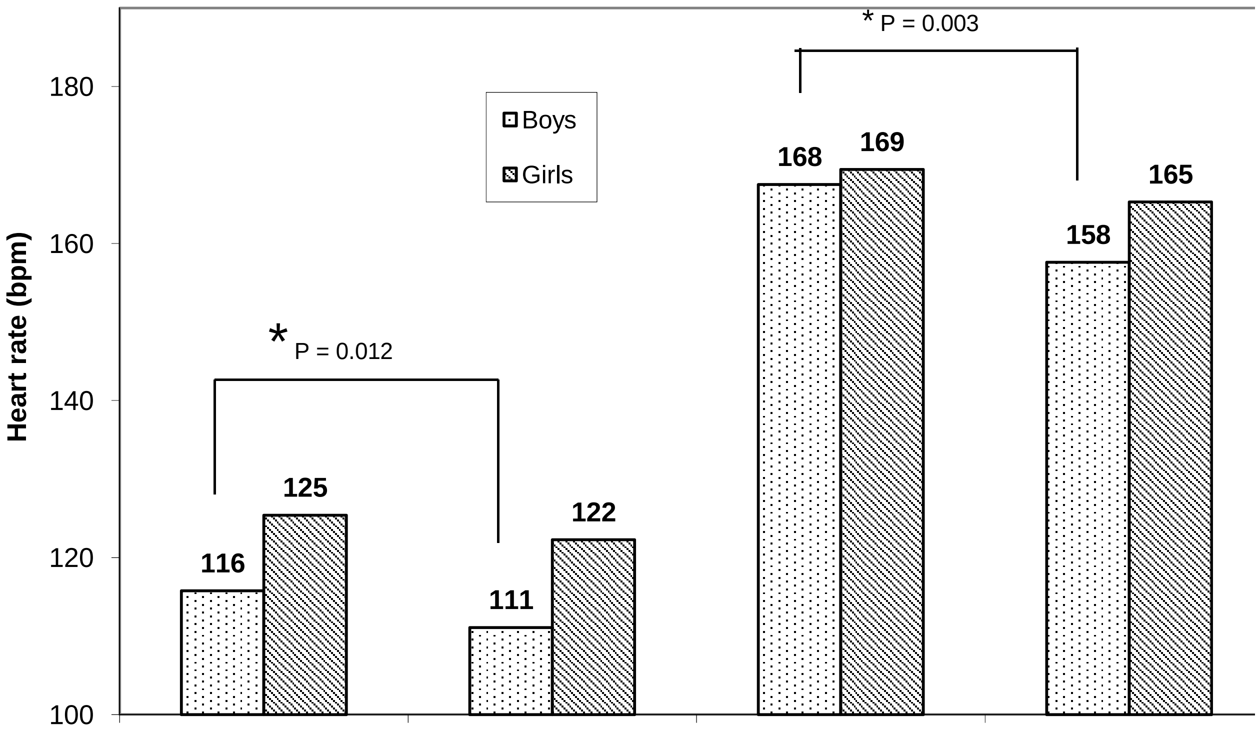


Figure 6-1. Submaximal responses to the exercise test.

Heart rate at 50W and 100W was significantly reduced at 12 weeks for the boys compared to baseline. In the girls there was a non significant trend for a reduced HR at 50W and 100W. On average HR at 50 W reduced by 4.25 ± 4.94 bpm and 3.13 ± 10.5 bpm for the boys and girls respectively. At 100W, HR reduced by 9.41 ± 9.63 bpm and 4.73 ± 13.9 bpm for the boys and girls respectively. Repeated measures analysis revealed a main effect of time for heart rate at 100W ($F = 4.748$, $P=0.039$).

6.5.4 Secondary outcome measures

Secondary outcome measures included lifestyle behaviours such as physical activity and dietary intake. Physical activity was objectively measured for five days using an Actiheart monitor and averaged in terms of activity counts, time spent in MVPA and energy expenditure. At baseline there were significant gender differences in physical activity with boys spending more time engaged in MVPA, expending more physical activity energy expenditure (PAEE) and accumulating more activity counts. At 12 weeks, the boys remained more active compared to the girls however both groups increased their activity from rest (Table 6.3). For the boys, whilst all measures of physical activity increased with time, these differences were not significant probably due to the low numbers of boys who completed the study. The girls significantly increased their activity counts and time spent in MVPA, increasing from 38 minutes at baseline to 64 minutes at follow up (Table 6.3). The average time spent in MVPA increased to such a level that the majority of girls at the end of the intervention exceeded the government guidelines for MVPA of 60 minutes per day (47). PAEE and total energy expenditure (TEE) both increased from baseline to follow up; however differences were not significant despite the large increases in physical activity (Table 6.3).

Table 6-3. Intervention changes in physical activity behaviour.

	Boys (n=12)			Girls (n=16)			F Statistic	
	Baseline	**12 Weeks**	**Change**	**Baseline**	**12weeks**	**Change**	**Time effect**	**Time-gender**
Physical Activity behaviour								
Physical activity counts (CPM)	46.3 ± 20.1	64.4 ± 25.8	18.2 ± 36.5	32.5 ± 10.3	44.5 ± 17.4**	12.0 ± 13.9	9.26 (p=0.005)	0.385 (p=0.540)
PAEE (kcal/day)	787 ± 415	981 ± 461	194 ± 714	632 ± 275	672±236	40.2 ± 227	0.94 (P=0.343)	0.289 (p=0.596)
TEE (kcal/day)	2475 ± 634	2637 ± 619	167 ± 969	2249 ± 399	2300 ± 393	50.7 ± 223	0.48 (p=0.496)	0.089 (p=0.768)
MVPA (mins)	66.9 ± 37.8	98.7 ± 63.0	31.8 ± 57.4	26.7 ± 25.7	64.6 ± 40.0**	37.8 ± 30.0	4.93 (0.035)	0.378 (0.544)
% MVPA	4.65 ± 2.63	6.85 ± 4.37	2.21 ± 3.99	2.55 ± 1.79	4.49 ± 2.76**	1.93 ± 2.09	5.51 (0.027)	0.266 (p=0.611)
Sedentary Behaviour and dietary intake								
Daily Time (mins)	374 ± 104	311 ± 81.9*	-63.2 ± 106	254 ± 121	208 ± 115**	-45.6 ± 58.1	11.8 (p=0.002)	0.332 (0.569)
% Sedentary	26.0 ± 7.24	21.6 ± 5.69	-4.44 ± 7.37	17.6 ± 8.40	14.5 ± 7.98**	-3.17 ± 4.04	11.8 (0.002)	0.332 (0.569)
Daily intake (kcal)	1501 ± 480	1856 ± 343	355 ± 644	1515 ± 398	1567 ± 297	51.8 ± 262	5.08 (p=0.033)	0.293 (p=0.099)
Fat (g)	61.3 ± 35.0	73.5 ±26.4	-12.2 ± 41.7	54.1 ± 24.6	65.2 ± 10.5*	11.1 ± 20.8	0.451 (p=0.451)	0.008 (p=0.930)
Fat (%)	35.6 ± 12.9	34.8 ± 7.04	-0.74 ± 12.3	33.9 ± 6.45	38.2 ± 4.28*	4.25 ± 7.11	0.895 (p=0.353)	1.841 (p=0.186)
Saturated fat (g)	18.6 ± 8.79	26.3 ± 12.5	7.73 ± 13.9	19.8 ± 7.73	23.4 ± 5.27*	3.55 ± 6.27	3.45 (p=0.075)	1.15 (p=0.293)

CPM, counts per min;; PAEE, physical activity energy expenditure; TEE, total energy expenditure; PAL, physical activity level (TEE/REE); MVPA, moderate to vigorous physical activity; % MVPA, percentage of time in MVPA. *P<0.05, **P<0.01, within group differences across time. [a] P<0.05 between gender difference.

At baseline boys spent significantly more time engaged in sedentary behaviours compared to the girls, spending on average over 5 hours a day either watching television or playing on a personal computer. By 12 weeks this had decreased to 5 hours per day which still vastly exceeds the guideline level of 2 hours per day (257). There were no differences in dietary intake from baseline to 12 weeks however for the girls there was a significant increase in fat intake across time. It was of interest to see how the change in body composition was related to participation in physical activity. Change in body fat % was therefore plotted against the change in MVPA (see figure 6.2).

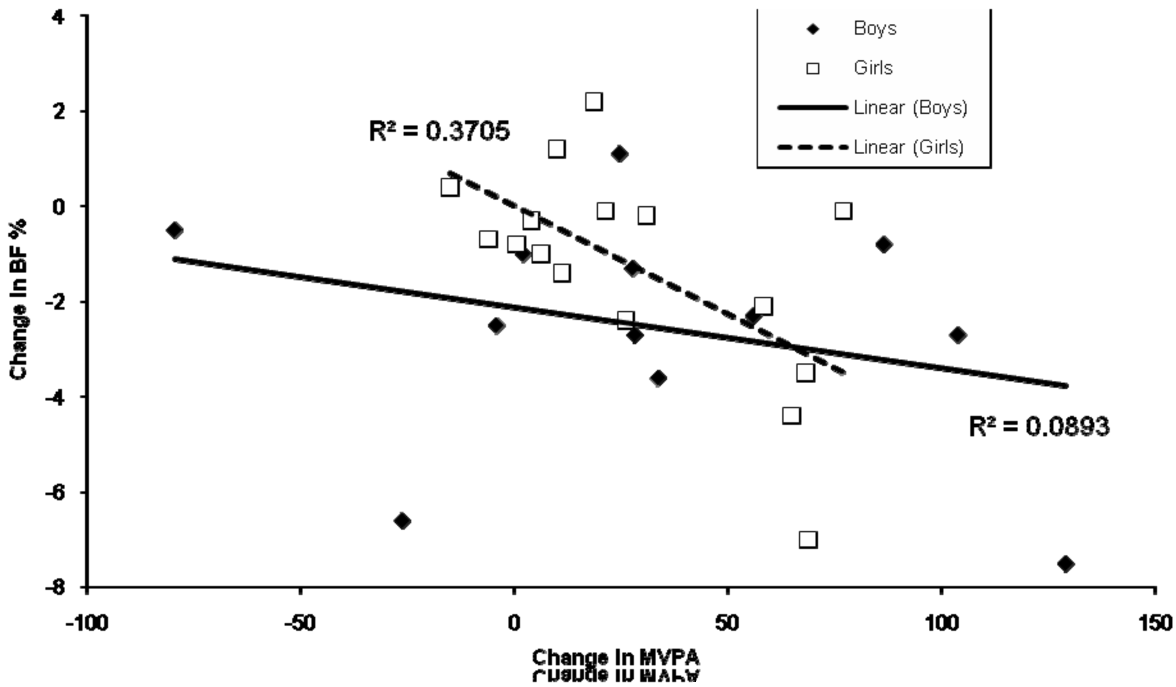


Figure 6-2. Change in MVPA plotted against change in BF% over the 12 week intervention.

There were no indications of meaningful relationships between change in MVPA and body fat % over time for either the boys or the girls.

6.6 Discussion

The most significant benefits of a 12 week dance mat intervention in obese children and young people were reductions in BMI SDS and body fat %, an increase in fat free mass and improvements in physical fitness. The decrease in fat mass was about equal to increases in fat free mass both in boys and the girls implying that fat mass in both genders is most likely replaced by a net gain of muscle mass and increased muscle strength. In addition, lifestyle physical activity increased to such an extent that on average the majority of participants exceeded Government guidelines for MVPA participation. Submaximal heart rates at workloads of 50W and 100W were also reduced in both groups, but only significantly for the boys. The observed reductions in heart rate at workloads that are part of daily living conditions (233) may reduce the tendency to avoid these activities in daily life and may contribute to further fitness gains in obese children taking part in exercise interventions.

To date, interventions using interactive forms of media such as the dance mats have been limited by poor adherence and high attrition. In the present study, 6 participants failed to complete 12 week assessments, an attrition rate of 17%. A previous study using dance mat exercise in younger children observed an attrition rate of 41% after 12 weeks (258) whilst an alternative study found that although all children remained in the study, adherence to the exercise prescription was poor (167). The accurate measurement of adherence to home-based exercise interventions is limited by reliance on self-report. Participants were asked to record their dance mat exercise in a diary and weekly phone calls or emails were made by the principle researcher to remind them. According to the diary data, 46% of participants failed to achieve an average of 20 minutes dance mat exercise on four days of the week. However at baseline and following the six and twelve week appointments physical activity was objectively measured in all participants with an Actiheart monitor. Accumulation of MVPA was deemed to provide an estimate of adherence to the exercise prescription with all bar two participants (93%) achieving >20 mins/day MVPA at six weeks increasing to 96% by twelve weeks. At baseline, 20 mins/day of MVPA was achieved by 76% of the participants suggesting that although not all of the participants achieved the desired amount of dance mat exercise, general physical activity increased to such a level that the overall prescription was mostly met. In future it would be good to ask the participants to record the specific times that they are performing the dance mat exercise during weeks 6 and 12 so that these times could be highlighted from the Actiheart. This would allow for the energy expenditure of the dance mat exercise to be compared to the energy expenditure of lifestyle activities and try to explain which contributes more to the increased activity levels. Reasons given for non-completion of the intervention included a lack of time, boredom, and swine flu affecting a child’s ability to exercise. The most common barriers to exercise reported by obese children and young people typically include body consciousness and a lack of access to facilities neither of which were cited here. This would indicate that in general dance mat exercise is a feasible and achievable mode of exercise for a previously sedentary population.

The energy expenditure of the dance mat exercise has been previously assessed in non-obese children and young people with results suggesting that the increase in energy expenditure in lean populations was not enough to increase fitness (259). We therefore performed a study (**chapter 5**) involving lean, overweight and obese young people and obese children. Obese and sedentary populations are likely to benefit most from this kind of activity as it can be performed within the home. The obese children investigated in **chapter 5** involved a sample of the children investigated in the present study. In all groups, dance mat exercise increased energy expenditure over rest, achieving a MET score >3 METs, the cut-off for moderate intensity physical activity (255). Dance mat exercise was sufficiently intense in the obese children and young people to achieve American College of Sports Medicine (ACSM) guidelines (50% HR_{MAX} and 55%$VO_{2RESERVE}$) for improving and maintaining cardiorespiratory fitness. The effectiveness of dance mat exercise in children is demonstrated in the present study with substantial improvements observed in VO_{2PEAK} in all children. For the boys the average improvement was 15% from baseline and for the girls, the improvement was 18%. A review of aerobic training interventions in children concluded that on average training leads to a significant 5-6% improvement in VO_{2PEAK} with an exercise intensity of >80% VO_{2PEAK}. However the review did not specify the presence of overweight or obesity and it may be that lean children are sufficiently fit at baseline and therefore show smaller improvements in fitness. The idea of a greater exercise intensity requirement for fitness improvements was also employed by researchers in Finland who compared the effects of aerobic interval training with lifestyle advice in a sample of overweight adolescents (260). The aerobic interval training took the form of very short bursts of very high intensity walking/running up a hill and was completed twice a week for 3 months. VO_{2MAX} increased more in the aerobically trained group increasing by 11% at 3 months. This was accompanied by reductions in percentage of body fat and mean arterial blood pressure (MAP). The authors suggested that high intensity exercise is more effective at getting a favorable body composition than moderate or low intensity with an increased amount of fat metabolized per unit time. The dance mat exercise in obese children was deemed to be moderately intense and heart rate was approaching 70% of maximum on average (255). Previous dance mat studies have often failed to include cardiorespiratory fitness as an outcome measure (167;248). However a more recent study of overweight children (aged 10 years) included measures of fitness and cardiovascular parameters such as flow mediated dilatation (FMD) and mean arterial pressure (MAP) (168). Mean VO_{2PEAK} increased by 2.38 ± 3.91 ml/min/kg, similar to that observed in the current study (table 6.2) and significantly higher than the negative change observed in their overweight wait-list control subjects. In the present study a submaximal measure of fitness was taken as heart rate at 50W and 100W. These workloads were chosen as they were achieved by the majority of children and are part of normal daily living conditions (233). Heart rate at 50W had significantly reduced by 12 weeks in the boys by an average of 4.25±4.94 bpm, while the reduction in the girls (3.13±10.5 bpm) was not significant. At 100 W, heart rate was significantly reduced in the boys by an average of 9.41±9.63 bpm, while the reduction in the girls (4.73±13.9 bpm) again was not significant. These reductions in submaximal heart rate are large and would suggest a shift in the cardiovascular regulation of exercise such that exercise stress is reduced (261). The exercise pressor reflex is a significant contributor to the regulation of the cardiovascular system during exercise. A peripheral neural reflex originating in skeletal muscle, the pressor reflex adjusts sympathetic and parasympathetic nerve activity during exercise. There is convincing evidence to suggest that an exaggerated exercise pressor reflex occurs in individuals with cardiovascular disease (261;262). Following the period of training and fat mass loss/fat free mass gain, the cardiovascular response to exercise was reduced substantially (Fig 6.3) in line with the expected effect of an efficient training intervention (262). This would result in a reduced exercise stress of a given workload for the children and thus it may become easier for them to perform physical activity in daily life. Although the values of VO_{2PEAK} for both groups remained relatively low after 12 weeks of intervention the increase would be sufficient for the participants to benefit in every day life and further improvements are likely to result if the intervention were to be continued for a more prolonged period.

The objective measurement of physical activity is important within exercise interventions so that changes in physical activity behaviour can be monitored accurately. A previous dance mat intervention study demonstrated a significant increase in vigorous PA with simultaneous reductions in light intensity PA (248). No changes were observed in MVPA over time nor were there any differences between the intervention and wait list control group in terms of MVPA. The children involved were on average 7 years old and had an average BMI Z score of 0.54 at baseline, so differ greatly from the participants involved in the current study. In general the children involved were very satisfied with the intervention and over half (54%) of parents believed that the DDR game did increase their child's PA and would therefore recommend it to others. In the present study, MVPA significantly increased in the girls going from 26.7 ± 25.7 minutes at baseline to 64.6 ± 39.7 minutes at follow up ($P<0.01$). The current Government guideline for physical activity participation in children and young people is 60 minutes of MVPA per day, and whilst at baseline this was achieved by only 35% of participants, at 12 weeks 64% achieved the desired amount. This is a considerable increase and approaching the nationwide average participation rate as highlighted by the Health Survey for England (3). There is an apparent variance in the amount of exercise reported by the self report diaries and the exercise displayed by the Actiheart suggesting that participants not only performed the prescribed exercise but also increased general physical activity. In the current study the exercise prescription for 20minutes of dance mat exercise on at least 4 days of the week, was less than previously observed (248). This prescription was chosen as it seemed feasible and achievable for the selected population and in addition based upon baseline levels of MVPA, an additional 20 minutes MVPA would allow the majority of children to achieve Government guideline levels of MVPA (47). One previous study failed to give the participants an exact prescription instead just providing them with the equipment and monitoring their physical activity over time (167). An alternative study gave a written prescription of 120 minutes per week of dance mat exercise which if performed on four days of the week equates to 30 minutes per day (248). Again this amount was selected as it was deemed feasible and would not replace any baseline activity. In fact, moderate intensity physical activity decreased over time though vigorous intensity activity increased and thus MVPA did not change. The children reported spending an average 89minutes per week engaged in dance mat exercise and thus it is likely the children were replacing activity with the prescribed activity. This was not the case in the present study with physical activity increasing in all participants regardless of their apparent adherence to the dance mat. However the increase in MVPA observed for the boys was not significant possibly due to the higher baseline physical activity for the boys compared to the girls and the smaller number of boys who completed the study.

Despite the large increases in MVPA, there were no real differences in energy expenditure expressed as either physical activity energy expenditure (PAEE) or total energy expenditure (TEE). PAEE is influenced by the body weight and fitness of the participant with heavier people experiencing a greater energy cost of a given activity. There is a limitation in the use of baseline measured REE throughout the study as the most important predictor of REE is FFM (227) and FFM changed by over 1kg on average. In a previous chapter it was discussed that the use of the Schofield equation in obese children is prone to underestimation in the girls and differs significantly from measured REE. However due to time constraints REE was only measured at rest and it was therefore assumed that by 12 weeks, REE would not have changed sufficiently to affect the estimation of TEE. It is likely that as the participants became fitter, they may have in fact increased REE, accompanied by increases in FFM increasing REE.

Sedentary behaviours are increasingly being implicated as contributing to the obesity epidemic through replacement of physical activity and promotion of increased dietary intake. However surveys have revealed that although children and young people are often aware of the health benefits of physical activity they are unwilling to give up time spent sedentary. Therefore active video gaming may allow for previously sedentary behaviours to increase energy expenditure and contribute to a person's physical activity. In the current study, baseline levels of sedentary behaviours far exceeded the American Academy of Paediatrics recommendations of <2 hours per day (257), with boys were spending an average of over 6 hours per day engaged in either television viewing or computer game use. Sedentary behaviour was assessed using self-report and is liable to recall bias however research has shown obese people tend to under report unhealthy behaviours rather than over report. By 12 weeks both boys and girls had reduced the amount of sedentary time, reducing by nearly one hour for the boys and 45minutes in the girls. Although these differences may seem vast and unrealistic, the same was observed in a previous study utilising dance mat exercise where sedentary screen time reduced by 4.2 hours/week on average.

In general, participants improved their body weight, BMI SDS and body composition as indicated by body fat % across the 12 week intervention period. There was a non significant trend for weight loss in the boys and weight maintenance in the girls however on average BMI SDS was significantly reduced. A previous study examining clinical measures of adiposity determined that changes in BMI SDS most accurately reflect changes in fat mass with a BMI SDS reduction of 0.25 indicating a fat mass loss of 2.9 %. In the current study, the average BMI SDS reduction was 0.11±0.14 in the boys and 0.07±0.096 in the girls. These changes were accompanied by significant reductions in body fat %; 2.53±2.46 % for the boys and 1.26±2.25 % for the girls. This is the first study utilizing dance mat exercise as an intervention to show average reductions in BMI SDS and favourable changes in body composition. Neither of the previous studies included obese children and study aims have focused more on reductions in sedentary behaviour and improvements in endothelial function than improvements in body composition (168;248). Weight gain rates were reduced over the 12 week intervention compared to a previous study (168) and this was accompanied by improvements in endothelial function, and physical fitness. A recent study in a similar population of obese adolescents involved in a hospital based weight management programme demonstrated that reductions in BMI SDS of at least >0.25 are required for improvements in body composition and cardio-metabolic health with greater benefit noticed if BMI SDS reduced by >0.5 (263).

There were no real differences in dietary intake observed other than an apparent increase in fat intake for the girls. Self-report of dietary intake is prone to bias especially in an obese population and is likely to be massively underreported. It has previously been suggested that obese people may increase their calorie intake in response to increased exercise as a form of ‘compensation’. It is difficult to say whether this has happened in the present study due to the inaccurate dietary intake however there was a non significant tendency for calorie intake to increase in the boys by an average of 220 ± 398kcal/day.

In conclusion it would appear that a 12 week dance mat exercise intervention is effective in promoting favorable changes in body composition, physical fitness and physical activity in a sample of morbidly obese children and adolescents. In general adherence to the program was good with 82% of participants completing their 12 week assessment. In addition the reasons given for non completion of the 12 week programme did not include body image awareness or lack of access to facilities which would suggest that dance mat exercise may be able to overcome some of the usual issues associated with exercise interventions in obese children and adolescents.

7 CHAPTER 7. THE EFFECT OF A 12 WEEK HOME BASED EXERCISE INTERVENTION ON PSYCHOLOGICAL WELL-BEING IN OBESE CHILDREN AND YOUNG PEOPLE.

7.1 Abstract

Objective: The aims of this study were to examine psychological well-being and motivation to exercise in a sample of lean and obese children and young people at baseline. Changes in psychological well-being were examined in response to a 12 week home based exercise intervention using playstation dance mats.

Participants: 34 obese children aged 9-18 years with BMI >95th centile for age and gender and 14 lean young people aged 10-18 years were recruited to participate. All obese children participated in the 12 week intervention with 28 providing follow up data at 12 weeks.

Procedure: All participants completed a questionnaire package at baseline designed to examine well-being and motivation to exercise. Body composition and physical activity were also examined. Obese children completed assessments at baseline and following a 12 week intervention.

Main outcome measures: Differences in psychological well-being and motivation to exercise between lean and obese children. Changes in psychological well-being in obese children in response to a 12 week exercise intervention.

Results: At baseline, obese children had significantly higher levels of social physique anxiety and reduced body-esteem in the weight and attribution domains compared to lean controls. Following 12 weeks of intervention, obese children displayed significant improvements in general self-worth and reduced social physique anxiety. Furthermore there was a trend for the obese children to become more self-determined in their motivation to exercise.

Conclusions: Obese children display impairments in body esteem and social physique anxiety compared to lean children which contributes to a reduced self-worth and hence reduced quality of life. A 12 week home based exercise intervention using playstation dance mats was sufficient to promote improvements in self-worth and social physique anxiety.

7.2 Introduction

The increasing prevalence of paediatric obesity is well documented, reaching epidemic proportions in much of the western world. Recent figures in the UK suggest that around 30% of 2-17 year olds are either overweight or obese with prevalence rates almost doubling from age 5 to age 11 years (3;264). Obesity in childhood is associated with significant risk for development of adult obesity, cardiovascular disease and type 2 diabetes, (18;214) with additional evidence suggesting a negative impact on functional health and well-being (128;130).

Health related quality of life (HRQOL) is commonly defined as an individual's quality of life associated with their physical, mental and social well being, and is a multidimensional construct which is increasingly used as an outcome measure in clinical trials (210;265). There is considerable evidence for a strong and significant relationship between paediatric obesity and impaired HRQOL (129;130) with some evidence to suggest the relationship follows a dose response pattern (129). A recent study demonstrated impairments in HRQOL in obese children and young people although parent proxy values were consistently lower than those reported by the children (130). Poor quality of life was demonstrated in all domains of functioning suggesting the day to day life of the obese youths to be significantly impacted by obesity, with a further study suggesting the HRQOL for obese children to be lower than that experienced by paediatric cancer patients (266).

Paediatric obesity is also associated with body dissatisfaction, depression, anxiety and low self-esteem which will all contribute to the above mentioned HRQOL (133-135). An intervention study identified a high proportion (30.3%) of obese adolescents to display scores on the Children's Depression Inventory (CDI) that were indicative of probable depression with 22% of them reporting suicidal ideations in the previous two weeks (136). A further study of obese youths found the prevalence of depression to be 11% when the most conservative criteria for depression was used, increasing to 34% when less conservative criteria were employed (130). The children reported a peer environment in which they were subjected to name calling and teasing about their appearance leading to them becoming socially marginalised. From a child's perspective, social isolation and stigmatisation will significantly impact upon day to day functioning and was related to the incidence of depression in this cohort. Furthermore perceived social support related to both the prevalence of depression and HRQOL.

A longitudinal study of the relationship between BMI and depression in adolescents found depressed adolescents to be at increased risk for the development and persistence of obesity during adolescence (135) suggesting depression or depressive mood to be a causal factor rather than a consequence of the obesity. This relationship survived adjustment for baseline BMI and physical activity with the odds ratio of becoming obese at follow up doubled if depressive symptoms were present at baseline. It may be that depressive mood impacts upon a persons attitudes to health behaviours such as physical activity and healthy diet, behaviours which are implicated in the development of obesity. Furthermore low mood and depression in childhood and adolescence are independently associated with binge eating and bulimia nervosa (267) such that dietary habits are worsened by an inability to control eating behaviour. Overweight teenagers have also been found to lack belief and confidence in their ability to engage in a healthy lifestyle (133) which may explain the lower levels of physical activity observed in this population.

There are multiple factors which contribute towards a person's ability to participate in healthy behaviours including beliefs, motivation, and access to the behaviours themselves. It is important to try and understand the determinants of physical activity participation especially in an at risk population such as obese children and young people to aid the development of appropriate interventions. One theory of motivation; the self-determination theory identifies the multidimensional perspective of motivation suggesting that three basic needs, relatedness, competence and autonomy need to be met in order for an individual to feel self-determined and motivated (268). This theory suggests that when an individual is autonomously motivated, they will experience more interest, excitement and confidence in their behaviour and therefore may be more likely to sustain behaviour change (204).

Overweight and obesity may also impact upon self-esteem and body dissatisfaction. Low levels of self-esteem especially in the physical appearance domain have been observed in children as young as 11 years old (134). In this example boys were found to score higher than girls on athletic competence, physical appearance and global self-worth regardless of weight status. When weight status was included, obese boys and girls were 2 and 4 times more likely than their normal weight counterparts to report low competencies in physical appearance and global self-worth.

Further risk of ill-being arises from the common social stigmatisation and bullying experienced by overweight and obese children and young people (137). Within the school environment, overweight students are more likely to achieve not only a lower grade point average but also more detentions, worsened school attendance and increased tardiness (137).

As demonstrated the presence of obesity in childhood and adolescence can have significant impact upon day to day functioning and well-being. Despite this mounting evidence, interventions to treat obesity often fail to address the psychological needs of children and young people focusing instead on health behaviours such as physical activity and dietary intake. Research has demonstrated that regular physical activity can have beneficial effects on psychological factors such as self-esteem and social physique anxiety as well as the well established physical benefits (269;270). Improvements in physical self-worth have been observed in obese adolescents undergoing an 8 week exercise therapy intervention however improvements were also observed in the adolescents assigned to the exercise placebo group (136). The exercise placebo group received the same level of contact with an exercise professional though participated in very low intensity exercise. This would suggest that the improvements in self-worth may have been due to the contact with a health professional rather than the exercise itself. A residential summer camp in the UK with the aim of changing the beliefs overweight and obese teenagers had about their exercise, eating and appearance, demonstrated significant improvements in global self-worth following 26 days of camp (271). The improvement in positive automatic thoughts was largely accounted for by the reduction in weight however it remains unknown if a specific amount of weight loss had to occur before the positive changes in well being were noticed. In addition to monitoring changes in well-being across an intervention, if physical activity is included in the intervention, motivation to exercise should also be assessed.

It is clear that the presence of obesity has significant impact upon psychological well-being across all domains including self-worth, physical appearance, and quality of life in children and young people with suggestions that girls are further affected. High rates of depression are observed in this population as is reduced quality of life. The day to day functioning of obese children’s lives are impacted by the presence of their obesity and often psychological ill-being leads to social stigmatisation, and reduced achievement at school. Research has demonstrated that perceived social support is related to improved quality of life and reduced incidence of depression. In addition there is evidence to support the beneficial role of exercise in the treatment of psychological morbidities (271). Therefore an exercise intervention which offers continued contact with an interested individual may provide a combination of exercise and social support to promote favourable changes in well-being.

7.3 Aims and hypothesis

The aims of this study were to examine psychological well-being and motivation to exercise in a sample of obese children and young people both at baseline and in response to a 12 week home based exercise intervention using playstation dance mats. At baseline the psychological well-being of the obese children was compared to a lean control cohort. The correlates of well-being and exercise motivation were examined at baseline and follow up.

It is hypothesised that at baseline obese children will have significantly increased social physique anxiety, significantly reduced body esteem and reduced self-worth. The level of obesity is likely to affect the level of psychological impairment and so it is hypothesised that BMI SDS will be related to measures of well-being. It is hypothesised that girls will display more impairments than boys especially when related to measures of body esteem and social physique anxiety. Adolescent girls are characterised by reduced self-esteem and an increased awareness of physical appearance (134) regardless of weight status though it is likely that the presence of obesity will further impact upon self-esteem. The exercise intervention is hypothesised to improve well-being through various pathways. Interaction with an interested individual may provide the child with social support to improve quality of life. Likewise, the exercise itself and potential reductions in BMI SDS and concurrent improvements in fitness will further act to reduce body related anxieties. The level of improvement in well-being related to body esteem and social physique anxiety are hypothesised to be related to changes in BMI SDS with larger improvements in BMI SDS related to larger improvements in self-esteem especially for the girls. Well-being measures may be more influenced by the child's perception of the exercise intervention and how well they engaged with it.

7.4 Methods

7.4.1 Recruitment

34 obese participants were recruited through the General Paediatric and Endocrine clinics at the Birmingham Children's Hospital (BCH). All children aged 9-18 years old who fulfilled the inclusion criteria (BMI SDS >95th percentile for age and gender) were informed of the study aims and objectives and invited to participate. Interested children and their families were provided with full study information and a week later, a screening telephone call was made. An appointment was made for the child and their parent to attend the BCH for completion of informed consent. In addition 14 lean children and adolescents were recruited through local health and fitness clubs to act as a lean, control cohort. Recruitment took the form of poster and leaflet advertisement. All participants attended the Clinical Research Facility at the Birmingham Children's Hospital where they completed the following assessments.

7.4.2 Inclusion/exclusion criteria

All children who had a BMI SDS that exceeded the 95th percentile for age and gender were eligible for the present study. Exclusion criteria were a refusal of the child and/or their parent to provide informed consent, the presence of learning difficulties and the presence of any medical condition that would prevent the child from exercising (e.g. severe asthma). As this was a pilot study, the eligibility criteria were designed to be liberal. All participants were required to provide informed consent prior to participation and all procedures were approved by the Black Country Research Ethics Committee. Lean, control children were recruited to take part in baseline assessments only (**chapter 4**).

7.4.3 Intervention

All obese children and young people underwent a 12 week home based exercise intervention prescription involving play station dance mats. Participants were provided with the Codemasters Dance Factory game (Codemasters UK) game for the Playstation 2, a dance mat and if necessary a Playstation 2 (Sony UK). An instruction manual was provided to all participants alongside a telephone number to contact in case of technical difficulties. The children were asked to perform the dance mat exercise on four days of the week for 20 minutes at a time. This prescription was selected as it seemed attainable and based upon the baseline levels of moderate to vigorous physical activity (MVPA) would increase physical activity participation to recommended levels (224). Children were asked to complete a weekly diary to record adherence to the dance mat exercise and also participation in other activities. The principle researcher made weekly telephone calls and emails to all participants to track progress and adherence.

7.4.4 Assessments

7.4.4.1 Demographics

All demographic information was collected via self-report during the clinic visit. Residential postcodes were used to obtain Indices of Multiple Deprivation as a proxy measure of socioeconomic status (3). Ethnicity was self-reported for at least 2 generations.

7.4.4.2 Anthropometry

Weight was measured in light clothing to the nearest 0.1kg (Tanita UK Ltd, Middlesex) and height was measured without shoes to the nearest 0.1cm using a wall mounted stadiometer (Seca UK, Birmingham). Body mass index (BMI) was calculated as weight (kilograms) divided by height (metres) squared (kg/m^2) with overweight and obesity defined according to the International Obesity Task Force (IOTF) guidelines equating to a BMI of $25kg/m^2$ for overweight and 30kg/m^2 for obesity at age 18 years. BMI standard deviation scores (BMI SDS) were calculated using the United Kingdom 1990 Growth Reference data (182). Body composition was measured using a TBF 410GS body composition analyser (Tanita UK Ltd., Middlesex, UK) which uses bioimpedance to estimate the amount of fat mass (FM), fat free mass (FFM), total body water (TBW) and body fat % of the participant. The TBF 410GS has previously demonstrated acceptable reliability against Dual energy X-ray absorptiometry in males and females of varying ages and weight status (183). All anthropometric measurements were performed following a 2 hour fast and all were carried out by the same person using the same techniques and equipment for each participant.

7.4.4.3 General Self-worth

The General Self Worth subscale of the Self-description Questionnaire (SDQII) was developed based upon the Rosenberg 1985 Self-esteem scale and has been demonstrated to be a valid and reliable measure of self-worth (coefficient of alpha: 0.80) (196). Children were asked to respond to 13 items which had been amended to be suitable for children on a 6 point Likert scale. The Cronbach's alpha within this sample was 0.73.

7.4.4.4 Positive and negative affect

The brief measure of positive and negative affect scale (PANAS) (272) provides independent measures of positive and negative affects and has been validated in the general UK adult population (273). Children were asked to respond to 9 items which measures positive affect on a 5 point Likert scale. Positive affect represents the extent to which an individual experiences pleasurable engagement with the environment and is characterised by emotions such as enthusiasm and alertness (27). Negative affect (NA) was measured by response to 11 items on a 5 point Likert scale and represents subjective distress and unpleasurable engagements. High NA is characterised by a number of aversive mood states such as anger, guilt and fear whilst low NA is a state of calmness and serenity. Both PA and NA were tested for reliability with PA achieving a Cronbach's alpha of 0.854 and NA 0.636.

7.4.4.5 Social Physique Anxiety

The Social Physique Anxiety scale (SPA) measures social physique anxiety, defined as the degree to which a person becomes anxious in social settings when they perceive their physique to be being negatively evaluated (197;198). A modified 9 item version of the 12 item Social Physique Anxiety scale was used with responses scored on a 5 point Likert scale with higher scores indicating a greater degree of Social Physique Anxiety (199). The Cronbach's alpha for the present sample was acceptable at 0.796.

7.4.4.6 Body Esteem

Feelings about ones own physique can be differentiated from feelings about ones general appearance and therefore the Body Esteem Scale for Adolescents and Adults (BESAA) was used to tap the three main factors associated with body esteem. General feelings about ones appearance (BE-appearance), weight satisfaction (BE-weight), and evaluations attributed to others about ones body and appearance (BE-attribution) were all assessed by the BESAA, which asked participants to rate how often they agree with a series of 23 statements using a 5 point Likert scale ranging from 'never' to 'always'. The BESAA has previously been validated in large samples (200). Reliability for each subscale was tested using the Cronbach's alpha and found to be 0.74 for the attribution scale, 0.61 for the appearance scale and 0.62 for the weight scale.

7.4.4.7 Behavioural Regulation in Exercise

Previous research applying the self-determination theory has shown that exercise behaviour becomes more internalised as a person becomes more self-determined. This suggests that when the three basic psychological needs; autonomy, relatedness and competence are met, the person becomes more self-determined, motivation guides behaviour and ultimately well being outcomes ensue. Therefore the Behavioural Regulation in Exercise Questionnaire (BREQ) was developed to identify these types of behaviours (201), and then modified in 2004 to include a measure of amotivation (202). The integrated regulation subscale from the Exercise Motivation Scale is also included (203). The questionnaire consisted of 23 questions scored on a 5 point Likert scale (from ‘not true for me’ to ‘very true for me’). The questionnaire assessed 6 behaviour types, amotivation, external regulation, introjected regulation, identified regulation, intrinsic regulation and integrated regulation, with additional assessment coming from the calculation of the Relative Autonomy Index (RAI). The RAI is a single score derived from the subscales that gives an index of the degree to which a person feels self-determined. A Chronbachs alpha reliability coefficient was computed for each of the 6 factors, amotivation (0.73), external regulation (0.74), introjected regulation (0.60), identified regulation (0.58), intrinsic regulation (0.49), and interjected regulation (0.63).

7.4.4.8 Intrinsic Motivation

The interest/enjoyment subscale from the Intrinsic Motivation Inventory is considered the self-report measure of intrinsic motivation and assesses interest and enjoyment in exercise (204). Participants respond to 7 questions (e.g. Exercising is fun to do) on a 5 point Likert scale. The Cronbach’s alpha was 0.53.

7.4.4.9 Moderate to vigorous physical activity

Participation in moderate to vigorous physical activity (MVPA) was assessed using an Actiheart combined accelerometer and heart rate recorder. The AHR is worn on ECG pads strapped to the chest and records acceleration and heart rate in 1 minute epochs for up to 11 days and is a valid measure of PA and energy expenditure in children and adults (185;187).

Participants were asked to wear the AHR at all times for 5 days including during sleep at baseline, 6 and 12 weeks. AHR data was exported into an excel file and analysed using a pre-written MACRO. The data was summed as daily activity counts, average activity counts per minute, physical activity energy expenditure (PAEE), total energy expenditure (REE + PAEE), and time spent in moderate to vigorous physical activity (MVPA).

7.4.5 Analysis

All variables were equated and tested for reliability using the Cronbach's alpha with acceptance taken as >0.6. Normal distributions were checked for using the Shapiro-Wilk with P>0.05 taken as the level of significance. Due to the small numbers involved, non-parametric tests were performed to test for differences between lean and obese cohorts. All data are expressed as medians and minimum and maximum values. The Kruskal-Wallis test was used to test for differences between several independent groups. Mann-Whitney tests were used as Post-Hoc tests to determine where the differences lay. The Bonferroni correction was applied to increase statistical power. Significance was set as P<0.05 for the Kruskal-Wallis test and P<0.0125 for the Mann-Whitney Post-Hoc with Bonferroni correction (0.05/6 = 0.008). Gender differences were explored using independent samples t-test. Changes over time were explored using repeated measures analysis of covariance with changes in BMI SDS included as a covariate. All data are expressed as means ± standard deviation and significance was set as P<0.05.

7.5 Results

A total of 34 obese participants (17 boys, 17 girls) and 14 lean participants (5 boys, 9 girls) consented to participate in the study. According to 1990 British growth reference data, all obese participants exceeded the definition for obesity BMI> 95th centile (182), with 23% of the participants exceeding a BMI SDS >3.5, equivalent to morbid obesity or an adult BMI of

40kg/m^2. A total of 56% (n=19) of the intervention participants were of white ethnicity, 32% (n=11) were South Asian ethnicity and 12% (n= 4) were of black ethnicity. Of the lean cohort, 86 % were of white ethnicity with no SA participants recruited. Baseline characteristics and well-being variables are summarised in table 7.1.

Table 7-1. Baseline characteristics of participants.

	Males		Females	
	Obese (n=17)	**Lean (n=5)**	**Obese (n=17)**	**Lean (n=9)**
Age (yrs)	13.0 (11.0-16.0)	13.0 (12.0-17.0)	14.0 (9.0-17.0)	15.0 (12.0-18.0)
Weight (kg)	87.8 (45.4-119)	56.2 (38.8-82.9)	90.8 (62.2-128)	57.0 (47.2-76.1)*[c]
BMI SDS	2.96 (1.86-3.62)	1.05 (0.58-1.35)[a]	3.32 (2.02-4.27)	0.36 (-0.86-2.21)*[c]
Body fat %	36.1 (24.2-49.7)	19.2 (14.8-21.4)[a]	41.8 (32.3-54.0)	23.9 (14.8-33.8)*[c]
Positive Affect	35.0 (27.0-43.0)	43.0 (34.0-51.0)	34.0 (17.0-45.0)	35.0 (27.0-45.0)
Negative Affect	18.0 (11.0-34.0)	16.0 (10.0-25.0)	18.0 (10.0-43.0)	18.0 (14.0-33.0)
General self-worth	51.0 (33.0-70.0)	65.0 (57.0-71.0)	50.0 (27.0-72.0)	54.0 (20.0-63.0)*
Social physique anxiety	24.0 (13.0-37.0)	18.0 (17.0-22.0)	30.0 (18.0-41.0)	23.0 (20.0-37.0)
Body esteem_weight	1.50 (0.38-3.38)	2.63 (2.00-3.90)[a]	0.63 (0.00-2.0)[a]	2.50 (0.00-3.75)*[c]
Body esteem_appearance	2.2 0(0.60 -3.20)	3.10 (2.40-3.30)[a]	1.50 (0.60-3.10)	2.20 (0.40-2.90)*
Body esteem_attribution	1.60 (0.60-4.00)	2.20 (0.80-3.60)	1.20 (0.00-2.80)	2.00 (1.00-3.00)

** P<0.05 Kruskal Wallis test for differences. [a]- P <0.008 versus obese boys, [b] – P<0.008 versus lean boys, [c] – P<0.008 versus obese girls.*

As expected there were significant differences between lean and obese children in terms of body weight, BMI SDS and body fat %. Social physique anxiety was increased in both obese groups compared to lean, with the highest levels observed in the obese girls however no differences were significant. There were also between group differences in body esteem in the weight and appearance domain.

Motivation to exercise was assessed using the behavioural regulation in exercise questionnaire – 2. Baseline levels of motivation are summarized below (table 7.2).

Table 7-2. Baseline physical activity behaviour variables.

	Boys		Girls	
	Obese (n=17)	Lean (n=5)	Obese (n=17)	Lean (n=9)
Amotivation	0.50 (0.00-3.00)	0.00 (0.00-0.50)	0.25 (0.00-1.75)	0.00 (0.00-0.75)
External regulation	1.75 (0.25-3.50)	1.25 (0.50-2.25)	1.25 (0.00-2.75)	0.50 (0.00-1.75)
Integrated regulation	2.50 (1.75-3.50)	3.50 (3.00-3.75)	2.25 (1.25-3.50)	2.50 (1.00-3.75)
Relative Autonomy Index	6.67 (-4.08-16.2)	12.3 (10.5-16.2)[a]	6.00 (-2.83-15.3)	12.0 (5.58-17.8)

** P < 0.05 Kruskal wallis test for differences [a]- P <0.008 versus obese boys, [b] – P<0.008 versus lean boys, [c] – P<0.008 versus obese girls.*

External regulation, a measure of the extent to which people participate in physical activity in order to satisfy external pressures, was lowest for the lean girls, significantly lower compared to the obese boys. This would suggest that obese children and lean boys perform physical activity to fulfil external pressures. The various subscales of the Behavioural Regulation in Exercise questionnaire can be summed into a single score the Relative Autonomy Index (RAI) which gives an index of the degree to which an individual is self-determined. Obese boys were significantly less self-determined than lean boys.

7.5.1Intervention effects

Changes over time for measures of well-being were calculated separately for each gender and are displayed in table 7.3.

Table 7-3. Changes in well-being in response to a 12 week exercise intervention.

Outcome	Mean ± SD	F Statistic

	Males (n = 12)	Females (n = 16)	Time effect	Time * Gender effect
GENR *Baseline* *12 weeks*	 42.0 ± 4.10 56.7 ± 9.3[a]	 40.3 ± 4.70 50.7 ± 12.9[b]	31.8 (p = 0.00)	0.94 (0.34)
PA *Baseline* *12 weeks*	 35.2 ± 3.8 35.6 ± 6.2	 33.8 ± 6.4 35.4 ± 7.7	0.77 (P = 0.39)	0.28 (P = 0.60)
NA (Log) *Baseline* *12 weeks*	 1.33 ± 0.13 1.28 ± 0.14	 1.27 ± 6.4 1.25 ± 0.15	1.62 (P = 0.22)	0.28 (P = 0.60)
SPA *Baseline* *12 weeks*	 25.8 ± 6.0 22.8 ± 4.9[a]	 31.1 ± 6.10 27.5 ± 6.30[b]	17.8 (p = 0.00)	0.18 (P = 0.68)
BE_Weight *Baseline* *12 weeks*	 1.66 ± 0.5 2.04 ± 0.7	 1.32 ± 0.40 0.89 ± 0.66	0.019 (P = 0.89)	9.17 (P = 0.005)
BE_Appearance *Baseline* *12 weeks*	 2.00 ± 0.6 2.33 ± 0.05	 1.97 ± 0.70 1.75 ± 0.80[c]	0.062 (P = 0.81)	1.45 (P = 0.24)
BE_Attribution *Baseline* *12 weeks*	 1.75 ± 1.0 2.00 ± 0.8[a]	 1.36 ± 0.70 1.71 ± 0.60	4.73 (P = 0.039)	0.131 (0.72)
BMI SDS *Baseline* *12weeks*	 2.82 ± 0.52 2.63 ± 0.52[a]	 3.21 ± 0.67 3.10 ± 0.69[b]	17.9 (p=0.000)	0.899 (p=0.35)

GENR – General self-worth, PA – positive affect, NA – negative affect, SPA – social physique anxiety, BE_Weight, body esteem weight, BE_Appearance, body esteem appearance, BE_Attribution, body esteem attribution. a – P < 0.008 versus baseline males, b – P < 0.008 versus baseline females, c – P < 0.008 versus 12 week males.

A significant effect of time was apparent for general self-worth and social physique anxiety. All participants significantly improved well-being as indicated by these measures from baseline to 12 weeks. Body esteem for attributions increased from baseline for the males only, whilst body esteem for appearance increased in the males and decreased in the females resulting in a significant gender difference at 12 weeks. There was a trend for PA to increase and NA to decrease which may be a contributing factor to the observed improvements in GENR. When the repeated measures analysis was repeated for GENR and SPA with BMI SDS change included as a covariate, significance disappeared. This suggests that improvements in GEN-R and SPA were a result of the improvement in BMI SDS. The

Relative Autonomy Index (RAI) and its contributing components were assessed over time using a repeated measures design (table 7.4).

Table 7-4. Changes in motivation to exercise following a 12 week exercise intervention.

Outcome	Mean ± SD		F statistic	
	Males (n = 12)	Females (n = 16)	Time	Time * Gender
RAI			0.05 (P = 0.82)	0.37 (P = 0.55)
Baseline	4.99 ± 5.6	6.18 ± 5.3		
12 weeks	4.53 ± 7.4	7.18 ± 5.11		
Amotivation			0.015 (P = 0.90)	0.042 (P=0.84)
Baseline	0.96 ± 1.0	0.44 ± 0.5		
12 weeks	1.02 ± 0.9	0.42 ± 0.7		
Ex_Reg			0.028 (P = 0.87)	0.001 (P = 0.97)
Baseline	1.98 ± 0.9	1.20 ± 0.8		
12 weeks	2.00 ± 0.8	1.23 ± 0.7		
Intrin_reg			0.43 (P = 0.52)	0.43 (P = 0.52)
Baseline	2.75 ± 0.8	2.30 ± 0.9		
12 weeks	2.75 ± 0.9	2.52 ± 0.9		
Inter_reg			0.41 (P = 0.53)	0.005 (P = 0.94)
Baseline	2.40 ± 0.6	2.08 ± 0.6		
12 weeks	2.46 ± 0.7	2.16 ± 0.8		
MVPA			12.7 (P = 0.001)	0.056 (P = 0.82)
Baseline	69.1 ± 52.6	38.5 ± 26.0		
12 weeks	98.7 ± 63	64.6 ± 40		

RAI – Relative Autonomy Index, , Ex_reg – external regulation, Intrin_reg – intrinsic regulation, Inter_reg – interjected regulation. a – P<0.008, versus baseline.

There were no apparent changes in motivation to exercise over time.

7.6 Discussion

In conclusion the present study has shown that obese children and young people demonstrate significant impairments in psychological well-being when compared to a sample of age match lean controls. In particular, impairments were observed for social physique anxiety with statistically significant differences only apparent between obese girls and lean boys and body esteem in the weight and appearance scales. General self-worth was non significantly reduced suggesting obese children to have a reduced quality of life. Furthermore, when motivation to exercise was assessed, lean children were significantly more self-determined and were more likely to perceive exercise as behaviour important to them.

The present study also demonstrated how a 12 week home based exercise intervention using Playstation dance mats can promote significant improvements in general self-worth (GENR) and social physique anxiety (SPA) in a small sample of obese children and young people. These changes were accompanied by small but significant reductions in BMI SDS and increases in MVPA for all participants. The Behavioural Regulation in exercise questionnaire (BREQ) was used to assess exercise behaviour with no improvements observed.

It has previously been observed that obesity can impinge upon psychological well-being with high rates of depression and low self-esteem observed in obese children and young people (130;274). Previous research has also demonstrated gender differences in well-being especially when associated with body esteem and SPA (275). Furthermore studies have shown females to report lower levels of self-esteem relating to physical appearance (134) and lower quality of life even after adjustment for BMI (265). In the present study there were no gender differences in any variables between the lean boys and girls though there were gender differences in the obese group. The lack of gender difference for the lean children may be due to the small numbers and potential recruitment bias. All children were recruited through local health and fitness clubs and were therefore more active than the general population. Previous research has shown that less physically active children have lower psychosocial and total quality of life regardless of weight status (276). Therefore differences between lean and obese could be as a result of the reduced physical activity levels in the obese children and not the weight status of the children.

Over the course of the 12 week intervention, all participants significantly improved general self worth and reduced social physique anxiety whilst the boys also increased their body esteem on the attribution scale. There was no control group so it cannot be said whether the intervention effect was a result of the exercise itself or the involvement in the intervention and interaction with a health professional. In previous research involving obese adolescents exposed to either 8 weeks of exercise therapy or exercise placebo or usual care, significant improvements in physical self worth were observed for both the exercise therapy and exercise placebo groups relative to usual care (136). The very low intensity of the exercise placebo group would suggest that the improvements in self-worth were due to the contact with a health professional rather than the exercise itself. In the present study there were small but significant reductions in BMI SDS and increased time spent in MVPA which would improve the physical health of the participants. A residential summer camp for the treatment of obesity in children and young people employed cognitive strategies to promote long term maintenance of lifestyle behaviour change (271). A mean duration of stay of 26 days resulted in a mean weight loss of 5.7kg which was accompanied by significant increases in global self worth. In addition, the number of negative automatic thoughts reduced and there was a concomitant increase in positive automatic thoughts which was largely accounted for by the reduction in weight. The longevity of these changes is yet to be known, as is whether there is a threshold weight loss required for improvements to be seen. In the current study the significant improvements in self-worth and SPA were largely accounted for by changes in BMI SDS as significance disappeared when BMI SDS was included in the analysis as a covariate. Furthermore all children increased physical activity which has previously been shown to promote improvements in self-esteem (277). Although after 12 weeks, the GENR and SPA of the obese children were not equivalent to the values observed in the lean children, the improvements observed would be sufficient to improve quality of life. The obese children have reduced levels of anxiety they experience in relation to their body and improved general feelings of self-worth. In combination with improvements in body composition and physical fitness, the overall health related quality of life for the children will improve.

Although eating behaviours were not assessed and so the prevalence of binge eating and bulimia nervosa is unknown, it is likely that the presence of obesity and low self-worth in the children at baseline may have caused disordered eating (267). It would be interesting to examine differences in the prevalence of disordered eating between obese and lean children and also to examine whether the intervention could reduce the prevalence of binge sessions and disordered eating. There is a lack of research examining the most effective mode of treatment for disordered eating in children and young people however there is evidence for the role of cognitive behaviour therapy (278). The role of exercise in the treatment of binge eating remains unknown, however the observed improvements in self-worth following the intervention in the present study may have impacted upon eating behaviours.

There were no observed changes in motivation to exercise. It has previously been shown that autonomous motivation predicts participation in MVPA and so interventions should focus on fostering an environment which will promote autonomy, relatedness and competency which should help individuals to become more self-determined in their actions. No improvements in exercise behaviour were seen, however the intervention focused upon promoting exercise behaviour rather than fostering a motivational climate and therefore significant changes would not be expected. Due to the apparent relationship between motivation to exercise and exercise behaviour it may be useful for interventions to be developed to achieve an environment that supports autonomous motivation and encourages the individual to become more self-determined. This may lead to sustained behaviour change which is the ultimate aim of obesity interventions.

In summary, it would appear that a home based 12 week exercise intervention can promote moderate increases in general self-worth and intrinsic motivation and reduce social physique anxiety in a sample of obese children and young people. The changes appear to be largely accounted for by reductions in BMI SDS and increases in MVPA. Importantly the intervention did not provide any form of psychological input, instead focused on providing a supportive environment and regular contact with a trained individual. This may be more beneficial for improvements in psychological well being than exercise itself however the exercise is required for physical improvements. The 12 week intervention went some way to reducing the psychological impairments observed at baseline between lean and obese children and reductions were sufficient to improve quality of life.

8 CHAPTER 8. GENERAL DISCUSSION

8.1 Overview

The primary aims of this PhD thesis were to examine the metabolic and environmental determinants of obesity in children and young people with particular reference to lifestyle behaviours such as physical activity and dietary intake. **Chapter 4** aimed to identify these determinants which in combination with previous research were used to develop a novel intervention for the management and treatment of obesity in a sample of children and young people recruited from within the Birmingham Children's hospital. It was hypothesised that reduced physical activity is associated with and is a major contributor to the development of obesity in children and young people. Furthermore it was hypothesised that a simple exercise intervention using playstation dance mats could lead to demonstrable reductions in fat mass independently of reduced calorie intake.

Recent advances in video gaming have led to the development of interactive 'exergames' which increase the energy expenditure of the player. These games include ideas such as the Nintendo Wii and the Dance Dance Revolution concept. Their popularity cannot be denied with over 22 million Nintendo Wii Fit boards sold worldwide and increasing use in the commercial and public sectors. However their effectiveness as an exercise tool to improve and maintain fitness remains a contentious issue. Previous research has evaluated the energy demands of these 'exergames' finding that whilst energy expenditure increased above rest, it was not sufficient to improve cardiovascular fitness (165;259;279). However studies to date have so far failed to include the population who would perhaps most benefit from this type of activity; obese and sedentary children. Therefore **chapter 5** aimed to establish the energy demands of dance mat exercise in a sample of obese children and young people. The results of this chapter led to the development of a 12 week home based exercise intervention (**chapter**

6) which aimed to improve upon previous dance mat intervention studies. Prior work has been limited by technological problems, boredom and high attrition rates and therefore a game was chosen that allowed for participants to input their own music. Adherence was objectively assessed using the Actiheart combined heart rate and accelerometer and outcome measures were comprehensive.

There is substantial evidence for impairment in obese children and young people relating to psychological well being and psychosocial functioning (130). However there is also evidence that continued exercise can improve psychological outcomes, for example improving self-worth in a similar patient group (136;274). Studies which utilise measures of psychological outcomes often fail to include measures of physical improvement and therefore do not allow for causality to be inferred. Comprehensive measures of psychological well-being were assessed alongside the physical and lifestyle measures employed in the intervention study (**chapter 6 and 7**) to test the hypothesis that regular physical activity can improve well-being.

8.2 Chapter Summaries

8.2.1 Characterisation of study population

Numerous factors have been implicated in the development of obesity including genetic background and ethnicity; however lifestyle factors such as diet and physical activity are likely to contribute the most through their influence on energy balance. Obesity arises as a result of a chronic positive energy balance whereby energy intake consistently outweighs energy expenditure. Longitudinal studies have identified the protective role of physical activity in the development of obesity in childhood with evidence also apparent for the negative impact of poor dietary habits (29;59). Longitudinal studies allow for causality to be inferred and allow changes in behaviours to be associated with changes in physiological and metabolic outcomes. However cross-sectional studies also provide useful information on observed associations between behaviours. **Chapter 4** aimed to explore and describe the population of obese children and young people studied throughout this PhD thesis. A sample of 45 obese children and young people aged 9-18 years old were studied with a further sample of 15 lean young people aged 11-16 years recruited to provide comparison. Obese children significantly exceeded lean in all measures of adiposity including BMI SDS, body fat % and waist circumference. The prevalence of comorbidities was moderately high in the obese children with 52% displaying signs of raised fasting insulin and 47% with hypertriglyceridemia. These levels were similar to previously observed in obese children and provide strong evidence for the significant impact obesity in childhood has on current and future health (280). Further evidence for an impaired quality of life in obese children came from the measurement of cardiovascular fitness. Peak VO_2 values obtained by the obese children were less than half of those achieved by the lean children, and equivalent to those previously observed in 70 year old adults (223). This will have a significant impact on the day to day functioning of the obese children with even menial tasks feeling like maximal exertion. The low levels of fitness are probably explained by the low levels of physical activity participation observed. The lean children achieved an average of 181 minutes of moderate to vigorous physical activity (MVPA) per day therefore exceeding Government guideline levels of 60 minutes a day, however physical activity levels in the obese children were considerably lower. On average, obese girls achieved 30 mins MVPA per day, half of that recommended by the UK Government (3). Reported levels of dietary intake were much lower than measured expenditures indicating a level of systematic under reporting. Furthermore there may be some level of disordered or binge eating apparent in the obese children which were not reported

(267). Although depression was not measured, impairments in self-worth and body esteem observed in the obese children in **chapter 7** point to feelings of depression and shame, both of which have been linked to binge and disordered eating (267).

Accurate measurement of resting energy expenditure involves the use of sophisticated indirect calorimetry equipment and therefore a number of prediction equations have been developed, for example the Schofield equation (220). These equations use parameters such as age, gender and weight to predict REE using a regression equation developed in a specific population. However their applicability to other populations remains unknown. The Schofield equation was used to predict REE in all participants in **chapter 4** and was compared to indirect calorimetry measurement in all of the lean and 34 of the obese participants. The Schofield equation significantly underestimated REE in lean and obese girls and lean boys, whilst providing an overestimate in obese boys. The biggest discrepancy was observed in the lean girls for whom REE was underestimated by over 700kcal/day. Previous research has identified fat free mass (FFM) to be the predominant determinant of REE (227), which is affected by weight and body composition. This was confirmed in the present study through correlations performed which revealed significant associations between FFM and REE in the boys and between fat mass (FM) and REE in the girls. In the present study, lean children displayed reduced levels of FFM compared to the obese children though significant differences were only seen between lean and obese girls. Reflecting the differences in FFM, measured REE was higher in the obese girls compared to lean, however for the boys the lean children displayed the higher levels. This would suggest that for a given FFM, energy expenditure is decreased in the obese children. When average values for REE (kcal/kgFFM) are calculated it becomes clear that there are differences between lean and obese. Although numbers are small, indications of a reduced REE for a given FFM may point to a reduced capillary density and underperfusion of muscle fibres in the rested state (281) or may be a result of a reduced mitochondrial density or mitochondrial function. Impairments in skeletal muscle capillary density have previously been observed in obese populations, associated with reduced uptake of glucose following meal ingestion and reduced insulin delivery (281;282). Further impairments in skeletal muscle functioning exist in obese populations for example a reduced insulin stimulated microvessel recruitment. This leads to a reduced delivery and uptake of glucose into skeletal muscle (283) and ultimately may cause impaired glucose tolerance, an early indicator of type 2 diabetes. In addition to the reduced recruitment of microvessels, there is evidence to suggest that a reduced microvessel density is apparent which is linked to inflammation and increased risk of cardiovascular disease (284). Exercise training is hypothesised to cause an increase in the capillary density and perfusion of the microvasculature which may act to increase resting energy expenditure. Unfortunately, REE was only measured in the obese children at baseline and therefore any changes induced by the regular exercise are unknown. It can be hypothesised that the observed increases in FFM in the order of 2kg combined with a potential increase in capillary density and perfusion will have caused an increase in REE following the exercise training (285).

Chapter 4 also revealed potential ethnic differences between children of white and South Asian (SA) origin. Ethnic differences were examined in relation to body composition with South Asian children exhibiting higher levels of body fat for a given BMI when compared to white. There were also indications of ethnic differences in participation in physical activity and sedentary behaviour however small numbers limit the conclusions that can be drawn.

Correlates and associations between behaviours and health were examined with evidence of gender and socioeconomic differences apparent which warrant further investigation.

There is substantial evidence to suggest that adults with origins in South Asia (Bangladesh, Pakistan and India) experience higher rates of cardiovascular disease, higher cardiovascular mortality and an increased prevalence of type 2 diabetes (94;242;286) compared to the white UK population. Furthermore risk for the adverse comorbidities associated with obesity occur at a lower body mass index, leading to the publication of additional BMI points of interest for Asian populations (86) with BMI of $23kg/m^2$ and $27kg/m^2$ identified as overweight and obese for SA populations. To date the evidence base for children is less significant with a recent review concluding there to be insufficient evidence to support separate BMI definitions for obesity in children (287). However a study in lean, healthy children from the West Midlands identified higher levels of body fat % for a given BMI, reflected in higher levels of insulin resistance (88). Thus SA children who do not appear to be obese in fact have higher levels of body fat, reduced lean body mass and therefore an increased risk of early stage cardiovascular disease and type 2 diabetes. Furthermore prevalence rates of type 2 diabetes are much higher in children and young people of SA origin (96), presenting further evidence for a significant ethnic difference.

In the present study, **chapter 4** identified an apparent higher body fat % for a given BMI SDS in the SA children, although this difference was only observed for the boys at higher levels of BMI SDS. Although only small numbers were involved and there were a lack of SA children recruited into the lean control group, there are indications of an ethnic difference which warrant further investigation. In addition to the metabolic consequences of an increased body fat %, there are suggestions that a reduced lean body mass for a given body weight may result in a greater exercise stress and reduced exercise capacity. Moreover impairments in resting energy expenditure observed in SA populations are largely explained by differences in fat free mass (222). Further ethnic differences are also apparent in the distribution of adipose tissue with SA populations tending to deposit fat in the more metabolically active visceral region (87). Waist circumference is used as an indicator of visceral fat and has been shown to be a better predictor of cardiometabolic risk than BMI in SA populations. In the present study, although there were no significant differences between groups, waist circumference and body fat % were higher for both SA groups compared to the white UK indicating a higher metabolic risk. The additional metabolic risk from visceral fat is linked to the release of circulating inflammatory cytokines which cause an increase in the degree of insulin resistance at both the level of the muscle and microvasculature (288).

To date these ethnic differences have been largely explained by differences in genetic make up and potential metabolic programming in response to periods of feast and famine, however the contribution of lifestyle behaviours have not been extensively studied (85;289). There is evidence from within India that an urbanisation of lifestyle has led to dramatic increases in the prevalence of obesity and type 2 diabetes (290). This may be due to reduced lifestyle physical activity in urban areas which may also be contributing to the high prevalence rates of type 2 diabetes observed in UK South Asian populations. Surveys and subjective measures of physical activity have found some evidence of reduced physical activity levels in SA populations, with lowest participation rates observed for SA women (243).

In **chapter 4**, participation rates in MVPA were lowest for the SA girls however conversely SA boys displayed the highest participation. There was tendency of SA children to report higher dietary intake in the form of both total energy and fat intake which may go some way to explaining the higher body fat % observed. No children from SA origin were recruited into the control group which limits the generalisability of any findings. It has previously been noticed that recruitment of SA individuals into research is low, for example in the British Heart Foundation Family Heart Study, SA families represented only 2 % of the 2000 families included despite concentration in heavily SA occupied areas (291).

The presence of a lean control group allowed for differences between lean and obese to be examined. The lean control participants were recruited from local health and fitness clubs and therefore had an active interest in healthy living. In future, the recruitment of a lean, sedentary control group and if possible obese but active would allow for further factors implicated in the development of obesity to be examined. It would be of interest to see how measured energy balance varies between lean active, lean sedentary and obese sedentary. The predominant factors implicated in the development of obesity are physical activity and dietary intake, both of which were found to differ between lean and obese in the current study. It may be that the lean participants recruited were not representative of the general adolescent population as a whole. In addition, obese children were all recruited from within a hospital setting and were likely to be receiving specialist help for problems related to their obesity. The observed differences between the lean and obese participants may be exaggerated compared to differences observed in the general population. There were significant differences in the socioeconomic status of the lean versus obese participants with the lean females being significantly less deprived than their obese female counterparts. Furthermore, no children of

SA origin were recruited into the control group. Prior research has demonstrated the difficulty in engaging SA populations into research (291) however future research should focus recruitment in areas heavily populated with South Asians and develop ethnically tailored recruitment strategies.

Significant and substantial differences in physical activity participation were observed between lean and obese providing further evidence for the protective role of physical activity (57;64). At present the UK government recommends that all children participate in at least 60 minutes of MVPA per day, a figure that was achieved by all lean children and most of the obese boys (224). When time spent in MVPA was limited to accumulated time spent in bouts that exceeded 10 minutes in length to fulfil adult guidelines for MVPA participation, the number of children achieving the guideline level significantly reduced (209). There is some confusion as to whether lifestyle MVPA can be accumulated over the course of the day, or whether to obtain the health benefits of physical activity, bouts should be longer than 10 minutes in length. Future research should focus on identifying the actual amount and mode of exercise required for health benefits. This is especially important in children for whom physical activity is characterised by short bursts of spontaneous activity.

In comparison to previous research, levels of MVPA observed were similar. A study of slightly older obese and normal weight adolescents found MVPA to account for 7.4% and 12.7% of total time for the obese and normal weight children respectively, similar to the 7% and 12.6% observed in the obese and lean boys in the present study (292). MVPA levels were lowest for the obese girls, with an average of 35 minutes per day similar to that observed in a cross-sectional study of adolescent girls in the USA (59).

Limited recommendations can be made based upon the findings of **chapter 4** however children who achieved the current guideline levels of MVPA were significantly less obese and had reduced body fat than those who did not and therefore evidence is provided for the protective role of physical activity. Previous research has identified a strong link between sedentary behaviours and risk of obesity (293), which has led to the publication of guidelines recommending less than 2 hours of TV viewing per day for children and adolescents (257). In the present study all children exceeded these guidelines with obese children spending significantly more time engaged in sedentary pursuits compared to lean. Highest levels were observed in obese boys who spent over 5 hours a day sedentary.

In the present study compliance to the measurement of physical activity was good, however there were some issues with a loss of signal during the Actiheart measurement due to excess adipose tissue. Therefore recordings were only included if participants achieved greater than 16 hours of measurement. Furthermore there is some evidence to suggest that people can change their behaviour in response to the process of observation, termed the Hawthorne effect and hence at least 5 days of measurement were also required (53). The drastically low levels of MVPA observed in the obese children make it unlikely for them to have changed their behaviour or increased physical activity in response to wearing the Actiheart. However there is a possibility that lean children increased their physical activity behaviour over the measurement period. To minimise the potential of this happening, the first day of measurement was discarded with an average taken for the remainder of the measurement. There may have been an element of seasonal variation in levels of MVPA recorded (294) due to the time scale of the study. However the majority of recordings for **chapter 4** were made between January and May and therefore any seasonal effects were minimised. Every effort was made to ensure all recordings were taken during term time to keep behaviour constant.

8.2.2 The energy expenditure of dance mat exercise

In recent years the development of interactive forms of media such as the Nintendo Wii and playstation dance mats has provided a potential solution to increasing physical activity levels in previously sedentary populations. However before these tools can be promoted as beneficial for health, the actual energy demands need to be determined. Previously the energy expenditure of the Wii sports and dance mat games have been evaluated in healthy lean and overweight children (259;279). Despite recorded increases in energy expenditure above rest, intensity was not deemed to be sufficient to achieve ACSM guidelines for improving and maintaining cardiorespiratory fitness (177). As yet, there are no studies to evaluate the energy demands of dance mat exercise in obese, sedentary young people, perhaps the population who would most benefit from this type of exercise. Therefore **chapter 5** aimed to quantify the energy expenditure and relation to maximal effort of ten minutes continuous dance mat exercise in obese children and young people. Compared to maximal values, the exertion achieved during dance mat exercise achieved ACSM guideline levels, thus providing evidence for the promotion of dance mat exercise in this population. For all participants dance mat exercise exceeded 3 METs, the threshold for moderate intensity physical activity (190).

The study was limited by a lack of an age and gender matched control group. However, interactive computer and video games were developed with obese, sedentary populations in mind who may find it difficult to be physically active. The obese children demonstrated attaining ACSM guideline levels of VO_2 and HR for improving fitness during dance mat exercise and further evidence for this is provided by the substantial improvements in fitness observed in **chapter 6**. The energy expenditure of dance mat exercise was only performed at baseline in a sample of the obese children. Future research should measure the energy expenditure of dance mat exercise at baseline, and after 6 and 12 weeks of regular exercise to see how the energy demands change over time with improvements in fitness.

The present study differs from previous research as it utilises the population who may most benefit from this kind of physical activity, obese and sedentary children and young people. In addition the gold standard measure of energy expenditure, indirect calorimetry was utilised. Previous research has used a number of different methods to assess energy expenditure, for example accelerometers (246;259). Accelerometers are limited by an inability to detect upper body movement and though dance mat exercise is predominantly lower body, accelerometers may underestimate the energy demands. One previous study aimed to quantify the energy demands of an alternative form of interactive media, the Nintendo Wii, observing increases in energy expenditure that were not sufficient to achieve guidelines for PA participation (279). However the IDEEA (intelligent device for energy expenditure and activity) system was used to estimate energy expenditure. The IDEEA comprises a small recorder and a series of sensors attached to the lower body and therefore predominantly lower body movement is recorded. The Nintendo Wii activity is characterised by upper body movement and therefore the IDEEA is likely to underestimate energy expenditure. It is important that future research focuses on the accurate estimation of these types of activity in the appropriate populations before they are promoted as exercise tools. However the current study and a recent review would suggest that there is a role for ‘exergaming’ in overall exercise strategies as it may be an activity that is desirable for obese, sedentary populations (274).

8.2.3 The effectiveness of dance mat exercise for promoting favourable changes in body composition in obese children and young people

Following the results of the previous chapter, the third study (**chapter 6**) aimed to assess the acceptability and feasibility of a 12 week home based exercise intervention using playstation dance mats in the population described above (**chapter 4**). Outcome measures included body composition, physical fitness and physical activity. All participants were provided with the dance mat and game and where necessary a playstation. The exercise prescription was to perform dance mat exercise on at least four days of the week for at least 20 minutes at a time. This prescription was chosen based upon the findings of **chapter 4**, as if fulfilled the children should then achieve government recommended amounts of MVPA. Weekly phone calls or emails were made by the researcher and adherence was assessed by self-report and through the use of Actiheart monitors at weeks 6 and 12. Adherence was high compared to previous research although more boys failed to complete the intervention suggesting a gender difference in preferences. Statistically significant improvements were noticed in BMI SDS, body fat %, physical fitness and time spent in MVPA suggesting dance mat exercise to be a useful exercise tool in obese children. Dramatic improvements in cardiovascular fitness were observed in the region of 15% accompanied by reductions in heart rate at submaximal work loads. These findings would suggest a downwards shift in the exercise pressor response, resulting in a reduced cardiovascular response to exercise at lower intensities and hence greater ability of the children to perform exercise (261).

Numerous interventions have been developed for the prevention or treatment of obesity in childhood mainly focusing on the restoration of energy balance through increasing physical activity or reducing dietary intake. A recent systematic review concluded that there was limited data on the components of programs to treat childhood obesity that favour one program over another (158). More successful interventions tend to include multi-disciplinary support and offer dietary advice alongside methods to increase physical activity. High attrition rates are commonly observed in obese children in the region of 30%. There is a need for the development of interventions which are appealing to the population of interest. It is clear that children are spending increasingly large amounts of time engaged in sedentary pursuits such as television viewing and personal computer or video game use. If this sedentary time can be made active through the use of interactive media such as the Nintendo Wii and the Playstation dance mats, then adherence rates to exercise may be higher and MVPA may increase.

Previous attempts have been made to prescribe dance mat exercise in children, however success has been limited. One study was limited by a plague of technological issues, whilst the other noticed a significant tail in adherence over time suggesting boredom (167;248). Neither were targeted at obese, sedentary children who experience significant difficulty in performing physical activity due to a complex interaction of real and perceived barriers, for example body consciousness and lack of access to facilities (159). **Chapter 5** evaluated the energy expenditure of continuous dance mat exercise, finding it to exceed ACSM guidelines for improving and maintaining cardiovascular fitness, also exceeding the threshold for MVPA of >3METs (177;190). Based upon the findings of **chapter 5**, in **chapter 6** the long term effects of dance mat exercise on physical fitness were examined. At baseline and 12 weeks all participants underwent a cycle test to volitional exhaustion with continuous measurement of indirect calorimetry and heart rate (HR) used to identify VO_{2PEAK} and HR at predetermined submaximal work loads. At baseline, fitness levels were chronically low with values equating to those previously observed in elderly populations (223). This would suggest a high amount of stress to be placed on the cardiovascular system at low intensities of physical activity, making it harder for the person to achieve regular physical activity. Fitness was reassessed after 12 weeks of dance mat exercise and had increased by 3.76±1.52 ml/min/kg and 3.57±4.56 ml/min/kg in the boys and girls respectively. Although these changes appear small and VO_{2PEAK} values remain relatively low, they equate to percentage improvements of 15% and 17.8% from baseline. Such changes will be clearly noticeable during exercise and will make a dramatic input. Furthermore, heart rates at two predetermined submaximal workloads, 50W and 100W were reduced following the 12 week intervention. For the boys these reductions were substantial and significant, reducing by an average of 4.25±4.94 bpm at 50 W and 9.41±9.63 bpm at 100W. These differences are sufficient to significantly impact upon the participant's ability to perform regular activities such as walking and climbing stairs. Previous research testing the effectiveness of continued dance mat exercise has failed to include measurement of cardiovascular fitness (167;248) and therefore our study is the first to demonstrate that dance mat exercise, if sustained for a period of 12 weeks can promote improvements in fitness sufficient to improve daily functioning.

In terms of adherence to the exercise prescription there were some discrepancies between self-report and objective measurement. Self-report data indicated that only 54% of participants completed all prescribed exercise sessions however at week 6, AHR data revealed that in fact all but one child participated in at least 20 minutes of MVPA every day. Self-report is limited by a reliance of a person's ability to recall specific behaviours and often underestimates actual behaviour, especially in children for whom physical activity is characterised by sporadic bursts of short duration. It may be that the self-report diaries underestimated dance mat exercise or that the children increased their general levels of physical activity in response to participation in the intervention. Reasons for non completion were recorded as boredom, lack of time, and presence of swine flu. The gender differences in attrition pose an interesting question because in terms of outcome measures, the boys achieved greater favourable changes. Physical activity at baseline was higher for the boys compared to the girls, but change in physical activity was also higher so that by the end of the intervention the boys were achieving over 30 minutes MVPA per day more than for the girls.

In future, it would be beneficial for the children to record the times of day that dance mat exercise was performed so that the times could be highlighted in the AHR recording and actual energy expenditures calculated. The addition of a configured memory card to the playstation could allow for adherence to be monitored accurately and furthermore could be used to identify the times of participation allowing for energy expenditure to be calculated.

The study was developed as a pilot, feasibility study to determine the effect size of dance mat exercise which could be used for determination of sample size for a randomised controlled trial (RCT), and as a result no control group was included. In future it would be good to include an attention control group who received the same level of interaction with the research team to identify treatment effects and whether they are related to the exercise itself or involvement with an interested individual. To counteract potential issues with adherence in a control group, a computer game could be used which requires minimal effort and exertion and should therefore have no impact on fitness or body composition. Participants could be told the study aim was to identify the impact of computer game use on coordination and development which could encompass measures of body composition and physical fitness. Alternatively a wait-list control method could be used however this will probably limit the adherence of the controls to follow up measures. The results of prior work in a similar population found similar improvements in physical self-worth between obese children in the exercise and exercise placebo groups (136) suggesting contact with a trained individual to be potentially more important than the exercise itself. The energy demands of dance mat exercise were not evaluated in lean children, however it may be interesting to examine the effects of continued dance mat exercise in lean, sedentary children and young people. There may be differences between lean and obese children in the outcome improvements observed, and also in the adherence and motivation to perform the activity. The major benefit of dance mat exercise for obese children is that it can be performed within the home and therefore removes some of the barriers to exercise often observed. Adherence rates in **chapter 6** were relatively high considering the population involved, which suggests dance mat exercise may be an appealing form of exercise. However attrition rates were much higher for the boys suggesting dance mats to be more appealing for girls, though boys who did complete the intervention demonstrated greater improvements in outcome measures. Metabolic parameters were measured at baseline with high prevalence rates observed for some comorbidities. Due to the short time frame of the project and reluctance of the children to undertake blood tests, no repeat blood tests were performed at the end of the intervention and so the metabolic benefits of the exercise are not known, however vast improvements in fitness and a shift towards a lower cardiovascular response at lower intensities of exercise may indicate that improvements in insulin sensitivity may have been noticed had they been measured (295).

The significant results found in the current study were used to estimate a sample size required for an adequately powered RCT which would be able to detect significant differences between intervention and control. In the current study, 80-90% of cases significantly reduced body fat

%. In the RCT, if looking for 75% of cases to demonstrate reductions in body fat % compared with matched controls then a sample of 30 cases in each group would provide a 90% power probability for detecting a significant ($P<0.05$) difference between groups. A total sample of 60 subjects out of a target 120 subjects should allow for flexibility for matching requirements, non participation and drop outs.

It would appear that dance mat exercise is an attractive mode of exercise for obese, sedentary children and young people and is sufficiently intense to promote improvements in body composition and physical fitness. The long term effectiveness of this type of exercise remains unknown and previous research has suggested a boredom effect over time resulting in reducing participation rates (167;248). Future research should focus on the long term maintenance of these types of exercise.

8.2.4 The effectiveness of a home based exercise intervention for promoting favourable changes in psychological well-being

As well as the well-established physical and metabolic impairments associated with obesity in childhood, increasing evidence suggests psychological well-being to also be impacted upon (130). Therefore the final study **(chapter 7)** aimed to explore the changes in a number of parameters of well-being following the above mentioned 12 week exercise intervention programme. At baseline, the obese children were found to display significant impairments in well-being when compared to a sample of age-matched controls. In particular, impairments were observed for social physique anxiety and body esteem in the weight and appearance scales. Furthermore general self-worth was reduced suggesting obese children to have a reduced quality of life. Motivation to exercise was greater for the lean children, with them more likely to perceive exercise as being a behaviour that is important. Following 12 weeks of dance mat exercise, all participants demonstrated significant improvements in general self-worth and reductions in social physique anxiety. In addition, boys increased their body esteem on the attribution scale. Repeated measures analysis with BMI SDS included as a covariate identified the changes in general self-worth and SPA to be attributed to changes in BMI SDS suggesting greater changes in BMI SDS to be associated with greater changes in self-worth and SPA.

The psychological questionnaire completed in **chapter 7** identified that boys were more accepting of physical activity as being a behaviour they believed to be important to achieve. Moreover at baseline the boys were significantly less obese with an average BMI SDS of 2.74±0.53 compared to an average of 3.18±0.63 for the girls and average body fat percentage values at least 8 % lower than for the girls. It may be that success is determined by the obesity status of the child at baseline.

As this was a feasibility study, no control group was recruited to participate. In future it would be useful to have an obese inactive control who received the same level of interaction with a member of the research team but did not receive any exercise prescription. A similar study exploring the effectiveness of an exercise intervention in morbidly obese children, recruited an exercise control group who attended the same number of exercise sessions as the active group but heart rate was maintained below 40 % of heart rate reserve so that improvements in fitness should not be seen (136). In addition a usual care placebo group was also recruited to provide further comparison. No changes were observed in BMI SDS following the 8 week intervention or after 14 or 28 weeks of follow up. Improvements in physical self-worth were seen with the exercise group though were also seen in the exercise placebo group. This would suggest that the improvements arose as a result of the interaction with a trained individual rather than as a result of health-improving physical activity. The personal attention and social interaction experienced by the children as part of the intervention may have acted to improve measures of well-being and in addition the personal skills of the exercise trainer especially relating to enthusiasm, motivation and empathy are likely to impact upon the child.

Chapter 7 explored the psychological responses to the 12 week intervention but also examined correlates of well-being at baseline in both the obese children and a sample of lean, age matched controls. Psychological well-being is likely to change over time and therefore the inclusion of obese children who were not exposed to the intervention would allow for intervention effects to be identified. Furthermore, the inclusion of a lean cohort will allow for the influence of body weight on intervention changes to be examined. A comprehensive questionnaire package was developed to explore psychological well-being and motivation to exercise. However in future, it would be beneficial to include a measure of depression as a clinical manifestation of psychological ill-being.

8.3 Summary

In conclusion it can be said that the obese children and young people studied in this PhD thesis were significantly different from their peers in terms of body composition, physical activity, and physical fitness. Furthermore when compared to prior research, impairments in psychological well-being were evident especially in relation to body esteem and social physique anxiety.

Physical activity levels were chronically low in the obese children reflected in the drastically reduced levels of cardiovascular fitness. Metabolic abnormalities were present in a large proportion of the obese children as were psychological impairments indicating the significant impact of obesity on the children's day to day functioning. Therefore appropriate interventions need to be developed which are sufficient to promote improvements in body composition and well-being as well as encourage adherence and increased physical activity.

New forms of interactive media are gaining popularity as exercise tools and especially appeal to populations for whom regular exercise is difficult to achieve. Dance mat exercise was evaluated in obese children and young people and found to fulfil ACSM guidelines for improving and maintaining physical fitness (177). Therefore it was implemented as a 12 week exercise intervention with comprehensive outcome measures including body composition, physical activity and physical fitness. The exercise prescription of 20 minutes dance mat exercise on at least four days of the week was selected based upon the baseline levels of physical activity observed as this prescription was deemed to be sufficient to increase MVPA levels for the children to achieve UK Government guidelines (224). Adherence was higher than previously observed in similar populations though attrition was higher for the boys than the girls. Favourable changes in body composition and physical activity were observed following the 12 week intervention, with changes in physical activity reflected in vast improvements in physical fitness. Psychological well-being was also improved following the intervention principally in relation to body esteem and social physique anxiety.

These changes are likely to improve the quality of life of the participants. The improvements in physical fitness and reductions in submaximal heart rate will greatly reduce the stress placed on the participants during day to day activities thus making it easier to achieve regular physical activity. Furthermore the improvements in psychological well-being should improve the self-esteem of the participants and reduce the psychosocial impact of obesity.

The Nintendo Wii is fast gaining popularity as a health care product especially with the release of the Wii fit programme and numerous dance and sport games also available. The energy demands of the Nintendo Wii have been evaluated in healthy children with increases in energy expenditure apparent, however insufficient to improve fitness (162). However the device used to measure EE, the intelligent device for energy expenditure and activity system (IDEAA), is predominantly worn on the lower body and Wii activity utilises the upper body the most. Therefore EE may have been underestimated. Future research should evaluate the EE of Nintendo Wii activity in lean and obese participants and if sufficient to improve fitness a randomised controlled trial could test its effectiveness as an exercise tool. Prior research has identified a potential for boredom or repetitiveness when using forms of interactive media as a tool for exercise, therefore future research should also measure the long term effectiveness of these products.

To conclude, dance mat exercise appears to be an appealing and appropriate intervention for the promotion of physical activity in obese and sedentary children and young people. Regular dance mat exercise appears to promote favourable changes in body composition and well-being however the sustainability of these changes after the 12 week intervention are not known. However there is a need for a randomised controlled trial to test the long term effectiveness of dance mat exercise in obese children and young people before recommendations can be made regarding these types of activity.

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