Objectively Measured Physical Activity And Sedentary Behaviour In Young Children

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Declaration

I hereby declare that this thesis has been composed by myself, the work of which has been done by myself except where assistance has been acknowledged, that has not been submitted, either in similar or different form in any previous application for a higher degree, to this or any other university and that all sources of information have been specifically acknowledged by means of reference.

Louise A. Kelly BSc (Hons)

Declaration of Work Jointly Done

I would like to acknowledge Sarah Barrie and Gillian Milroy for their contribution with data collection for chapters 4 and 5 (comparison of two accelerometers for assessment of physical activity in pre-school children; cross-validation of the 1100cpm accelerometer output cut-off for measurement of sedentary behaviour) as part of their BSc undergraduate project.

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Study design protocols, data collection, data processing, statistical analysis and interpretation for all of the studies in this thesis was carried out by myself, under the supervision of Dr. John J. Reilly, Dr Stan Grant and Dr James Y. Paton.

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Abstract

Background: Regular physical activity in adults is recognised as an important behaviour and the health benefits of physical activity for adults are well established and noted in chapter 1. The direct relationship between physical activity and health for children and preschool children is less understood. This is partly due to methodological problems (Kelly *et al.*, 2004), leading to an interest in assessing and promoting physical activity among children (Troiano & Flegal, 1998; Reilly and Dorosty 1999). A report by Fulton et al (2001) for the US Centers for Disease Control and Prevention highlighted gaps in our current knowledge of physical activity patterns among preschool-age children, which are partly due to methodological problems.

Study 1: Aims: Compare the uniaxial MTI/CSA accelerometer and the biaxial Actiwatch accelerometer against direct observation of total physical activity and minute-by-minute physical activity in 3-4 year olds. **Methods:** MTI/CSA-7164 and Actiwatch accelerometers simultaneously measured activity during 35-45 minute sessions of structured play in 78, 3-4 year olds. Rank order correlations between accelerometry and direct observation were used to assess the ability of the accelerometers to assess total activity. Within-child minute-by-minute correlations were calculated between accelerometry output and direct observation. **Results:** For assessment of total activity MTI/CSA output was significantly positively correlated with direct observation (r 0.72, $p<0.001$), Actiwatch was not (r 0.16, $p>0.05$). **Conclusion**: The present study suggests that for epidemiological assessment of total physical activity in young children the MTI/CSA-7164 provides greater accuracy than the Actiwatch.

Study 2: Aim: To cross-validate the 1100 counts/ minute cut-off for the assessment of sedentary behaviour in an independent sample of young children using the MTI/CSA accelerometer. **Methods:** A previously developed cut-off for MTI/CSA accelerometry output (validation study) in 30 healthy Scottish 3-4 year olds, was cross-validated against direct observation in an independent sample of (n = 52) healthy Scottish 3-4 year olds.

Results: In the cross-validation study sensitivity was 83%: 438/528 inactive minutes were correctly classified. Specificity was 82%: 1251/1526 non-inactive minutes were correctly classified using this cut-off. **Conclusion:** Sedentary behaviour can be quantified objectively in young children using accelerometry.

Study 3: Aim: To carry out an exploratory study to test the hypothesis that socio-economic status (SES) in young British children may be associated with objectively measured levels of physical activity and sedentary behaviour. **Methods:** Paired comparisons were carried out for total physical activity, time spent in sedentary behaviour, light intensity activity, and moderate-vigorous physical activity (MVPA) between 39 affluent children (mean age 5.6 years SD 0.3) and 39 deprived children (mean age 5.5 years SD 0.5) from Glasgow, Scotland. Participants were matched for age, gender and timing of activity measurement. Physical activity and sedentary behaviour were measured objectively using the MTI/CSA accelerometer for 7 days (median monitored time 77 hours, range 38, 90). **Results:** Engagement in sedentary behaviour was high: affluent participants, 79% (range 68-90) vs. 78% (range 67-89) for the deprived participants (Wilcoxon signed ranked test, p=0.13). Median time spent in MVPA was identical between the affluent and the deprived participants: 3% (range 0-7) vs. 3% (range 1-9). **Conclusions**: This preliminary study does not support the hypothesis that there are major socio-economic differences in habitual physical activity and sedentary behaviour in early childhood.

Study 4: Aims 1: Describe habitual physical activity levels of rural Irish and urban Scottish children in terms of (a) total amount of activity (in counts per minute over monitored time), and (b) patterns of activity using established cut-offs (Puyau *et al*, 2002; Reilly *et al.*, 2003). **Aims 2:** To test the hypothesis that rural children are more active than urban children (study 4: chapter 7). **Methods:** Forty-one pairs (n=82) from a broadly socio-economically representative sample of children aged 4-5 years old (median age 5.3, range: 4.3 - 6.4 years) from Co. Carlow, Ireland and Glasgow, Scotland.

Total physical activity (mean accelerometer count/minute), sedentary behaviour (% of monitored time below 1100 counts/minute); and time spent in light intensity activity, and moderate-vigorous physical activity (MVPA) were assessed over 7 consecutive days using the MTI/CSA accelerometer, using Mann-Whitney or Wilcoxon signed rank tests where appropriate to test the significance of any differences in anthropometric characteristics, engagement in physical activity or sedentary behaviour between the Irish rural subjects and the Scottish urban subjects. **Results:** There were no significant differences in any of the anthropometric measurements ($P<0.05$) between the two milieus. Engagement in sedentary behaviour was high in both the Irish and Scottish children. There were no significant differences between the two groups for any aspect of physical activity or sedentary behaviour ($P<0.05$). This present study was the first to objectively measure physical activity and sedentary behaviour in Irish rural children. **Conclusion:** Contemporary rural Irish children may be physically inactive and engagement in sedentary behaviour was as high as in age-matched children from urban Scotland.

Study 5: Aim: To examine the tracking characteristics of physical activity and sedentary behaviour in a relatively large and relatively homogeneous sample of young Scottish children over a two-year period. **Methods:** Subjects were 21 boys and 21 girls (mean age boys 3.8 years SD 0.4 and girls 3.7 years SD 0.5). Total physical activity, MVPA and sedentary behaviour were measured objectively for 7 consecutive days at baseline, 12 and 24 months using the MTI/CSA accelerometer. Time spent in MVPA and sedentary behaviour was established using published paediatric cut-offs. In keeping with recent research in this area, tracking of physical activity, MVPA and sedentary behaviour were analysed in three ways: Spearman Rank correlations, percentage agreements and finally KAPPA statistics. **Results:** For total physical activity, Spearman rank correlations ranged from 0.17-0.35; for MVPA Spearman and rank correlations ranged from 0.22-0.37; and for sedentary behaviour Spearman rank correlations ranged from 0.17-0.35. Percentage agreement for total physical activity, MVPA and sedentary behaviour ranged from 24%-38%, 26%-38% and 26%-41% respectively. KAPPA statistics for total physical activity, MVPA and sedentary behaviour ranged from poor to fair. **Conclusion:** These results indicate low levels of tracking of total physical activity, MVPA and sedentary behaviour in young Scottish children over a two-year period.

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ABSTRACTS

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ABBREVIATIONS

CVD	Cardiovascular disease
EE	Energy expenditure
PA	Physical activity
BMR	Basal metabolic rate
DIT	Diet induced thermogenesis
BMI	Body mass index
CHD	Coronary heart disease
TG	Triglycerides
VLDL	Very low-density lipoproteins
LDL	Low-density lipoproteins
AR	Adiposity rebound
MET	Metabolic equivalent
RMR	Resting metabolic rate
DLW	Doubly labelled water
O_2	Oxygen
CO_2	Carbon dioxide
^{18}O	Oxygen 18
AEE	Activity energy expenditure
MVPA	Moderate to vigorous physical activity
VPA	Vigorous physical activity
DO	Direct observation
CPAF	Childrens physical activity form
CARS	The children's activity rating scale
CPM	Counts per minute
ASM	Activity score per minute
HR	Heart rate
RHR	Resting heart rate

PDPAR	Previous day physical activity recall
WT	Weight
HT	Height
Kg	Kilogram
M	Metre
SES	Socio-economic status
SPARKLE	Sport aiding medical research in kids: lifestyle and energy

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Research Profile

Published Papers Arising From This Thesis:

KELLY, L.A., Reilly, J.J., Fisher, A., Montgomery, C., Williamson, A., McColl, J.H., Paton J.Y., Grant, S. (2005) Effect of socio-economic status on objectively measured physical activity. Archives of Disease in Childhood (In Press).

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Chapter 1: Literature Review

1.1. General Introduction Defining Physical Activity

The epidemiological definition of physical activity still causes confusion. "Physical activity", "exercise", "sport", and "physical fitness" are, in fact, all distinct concepts. They are, however, often used interchangeably in both specialist and lay literature. This confusion in terminology has undoubtedly impeded a full understanding of physical activity, and sedentary behaviour, in children, and the consequent health consequences (Livingstone *et al.*, 2002).

The terminology has gradually been clarified and a broad consensus reached on how the various terms should best be defined (Caspersen *et al.,* 1985; Caspersen, 1989; Caspersen *et al.,* 1998; Powers *et al.,* 1990). As a consequence, physical activity is defined (in this thesis) as bodily movement produced by the contraction of skeletal muscle that increases energy expenditure above the basal level (Caspersen *et al.,* 1985; Caspersen, 1989; Caspersen *et al.,* 1998; Powers *et al.,* 1990).

Exercise is a sub-category of physical activity, and is defined as "planned, structured, and repetitive movements done to improve or maintain one or more components of physical fitness" (Caspersen *et al.,* 1985). Sport is another sub-set of physical activity and involves structured physical activity in competitive situations. It can be seen from these now widely accepted definitions that physical activity is a very broad construct that includes all kinds of movement, while exercise is more narrowly defined. Finally, for the purpose of this thesis, sedentary behaviour is defined as a state in which bodily movement is minimal (Dietz 1996). In terms of energy expenditure, sedentary behaviour represents a state where energy expenditure approximates to resting metabolic rate (Dietz 1996).

For adults, the health benefits of physical activity are well established (Pate *et al.*, 1995; US Department of Health and Human Services, 1996). These benefits include a reduction in morbidity and premature mortality from many of the leading causes of ill health, notably coronary heart disease. There are positive effects on many other aspects of health such as control of body fat and body weight, reduction of high blood pressure, decreasing the risk of colon cancer, facilitating blood glucose control, retarding osteoporosis, increasing muscle strength, promoting aerobic fitness, and counteracting depression and anxiety (European Heart Initiative, 2001). As a consequence, physical activity is now included in most health promotion recommendations. Given that adult chronic diseases often have their origins in childhood, there is a critical need for a better understanding of how physical activity and sedentary behaviour in childhood may shape health status in adulthood.

The direct relationship between physical activity and health is less clear for children and young people. This is partly due to methodological problems (Reilly *et al.*, 2003b; Kelly *et al.*, 2004; Riddoch *et al.*, 2004). However, more importantly, the main morbidities, which affect adults, and to which lack of exercise may contribute, have not generally become manifest because of the long time delay before unhealthy behaviours influence chronic disease. However, there is some suggestive evidence. Some pathological studies have reported advanced atherosclerotic lesions in young children, indicating that early signs of cardiovascular diseases (CVD) can be considered a paediatric phenomenon (Tracy *et al.*, 1995).

Much of the recent interest in assessing and promoting physical activity among children has been triggered from the well-documented increase in the prevalence of obesity in children (Troiano and Flegal, 1998; Reilly and Dorosty, 1999). The widespread alarm triggered by such reports has led to a substantial increase in research in the field. Numerous recent studies have found relationships between physical activity and numerous coronary heart disease risk factors (Anderson *et al.*, 2003; Sääkslahti *et al.*, 2004), body fatness, (Daniels *et al.*, 1999), high blood pressure (Davis *et al.*, 2002) and bone mass (McVeigh *et al.*, 2004).

1.2. Physical Activity: A Component Of Energy Expenditure

The laws of thermodynamics dictate that the energy entering a system minus the energy leaving equals the energy stored in the system. When the laws thermodynamics are applied this humans, it means that, energy taken in as food must be expended, or the excess will be stored, largely as body fat (Rolland, 1990). A mismatch in this equation between intake and expenditure results in underweight or overweight and obesity. DeLany et al (1998) noted obesity is the result of a sustained positive energy balance, a positive imbalance in energy being due to an increased energy intake, and/or decreased total energy expenditure

Three components of energy expenditure (EE) have been identified in humans: (i) Basal Metabolic Rate (BMR): typically represents about 60-70 per cent of the total EE. (ii) Diet Induced Thermogenesis (DIT): typically represents about 10 per cent of the energy content of food eaten at most (Powers *et al.,* 1990). (iii) Energetic Cost of Physical Activity (PA) accounts for the remaining 20-30 per cent of energy expenditure in typical humans living in Western societies (Powers *et al.,* 1990). The latter may vary strongly depending on the rate of voluntary activity (Powers *et al.,* 1990). Energy expenditure during activity varies enormously during an average day, from close to basal metabolic rate (BMR) while at rest in bed to more than 10 times the BMR during vigorous exercise. The energy expended through physical activity is the most variable component of total energy expenditure within and between individuals (Goran *et al.,* 1993).

1.3. The Obesity Epidemic

It is widely accepted that obesity has emerged as an epidemic in developed countries during the last quarter of the 20th century (Popkin *et al.,* 1998). Obesity is commonly defined in terms of body mass index (usually defined as BMI >30 in adults or above the 95th percentile in children) and is calculated as follows:

$$\text{BMI} = \left(\frac{wt(kg)}{ht(m)^2} \right) \text{ (NAO 2001; SIGN publication no.69, 2003).}$$

Data from almost every country in the industrialised world and even some from the third world reveal a growing proportion of adults are either overweight or obese (Bundred *et al.,* 2001; Flegal *et al.,* 2002; Hedley *et al.*, 2004). Approximately 50% of the adults in the US and Canada have a BMI >25kg/m^2. In some population subgroups in the US the prevalence of those with a BMI of 25kg/m^2 is greater then 70% (WHO, 1997).

There is also evidence of an upward trend in the proportion of the British adult population who are overweight and obese (Rennie and Jebb, 2005). Latest figures show that 23% of men and 25% of women were obese (defined as BMI >30kg/m^2) in 2002. The rapid increase in the prevalence of obesity in the UK parallels that which is occurring in the USA, indicating that the obesity epidemic will not be self-limiting. If current trends continue, more than a quarter of the British adult population will be obese by the year 2010. Within the UK there is some evidence that the prevalence of obesity may be higher in Scotland than England but, in general, regional differences in the risk of obesity are small (NAO, 2001).

1.4. Morbidity And Mortality Associated With Obesity

There is strong evidence to support a relationship between participation in regular physical activity and lower risk of disease. As previously mentioned, adults who exhibit higher levels of sedentary behaviour have an increased risk of coronary heart disease (Bijnen *et al.*, 1994), stroke, hypertension, non-insulin dependent diabetes mellitus (Pate *et al.*, 1995; US Department of Health and Human Services, 1996), osteoporotic fractures, and some cancers (Colditz, 1999). In each of these major medical conditions the adverse effect of sedentary behaviour is independent of body weight or adiposity (Colditz, 1999). As a consequence of this independence, the burden of sedentary behaviour can be added to that attributable to obesity (Colditz, 1999).

To address the full impact of behaviours such as sedentary behaviour on health and their consequences, one can summarise the burden of premature mortality. There is evidence of a strong inverse relationship between physical activity and total mortality among women (Kushi *et al.*, 2002). In England 30,000 deaths a year are linked to obesity (Vass, 2002).

While regular physical activity in adults is recognised as an important behaviour for preventing disease, the impact of sedentary behaviour on childhood health is not well documented. However, evidence suggests that some chronic diseases (e.g. obesity, coronary heart disease (CHD), and type 2 diabetes) may begin to develop during childhood and that childhood behaviours may be precursors of adult health behaviours (Fulton *et al.*, 2001). As in adults, childhood obesity results in high levels of serum triglycerides (TG), very low-density lipoproteins (VLDL), low-density lipoproteins (LDL) and low levels of high-density lipoproteins, which may influence propensity to atherogenesis (Parker *et al.*, 1991; Zwiauer *et al.*, 1992).

Pathological studies have reported advanced athlerosclerotic lesions even in children and there is increasing evidence that children's dyslipidaemia, obesity, hypertension and physical fitness track into adulthood (Riddoch *et al.*, 1995).

Sinha et al (2002) noted impaired glucose tolerance is highly prevalent among obese children and adolescents (BMI >95th centile), irrespective of ethnic group. Impaired oral glucose tolerance was associated with insulin resistance while beta-cell function was still relatively preserved. Non- insulin independent diabetes mellitus ("adult onset") is an increasingly common diagnosis in paediatric diabetes clinics throughout the US. Less common consequences of obesity, which are appearing more frequently in children, are hypertension, obstructive sleep apnoea and orthopaedic complications (Dietz, 1998). Since these factors tend to cluster i.e. group together in the same child and track i.e. persist with age, it seems inevitable that the identification of children at risk for adult obesity should lead to targeted early intervention. If successful, this would contribute to decreasing adult obesity and its associated complications (Parsons *et al.,* 1999).

More immediate effects of developing obesity in children include adverse/detrimental psychosocial outcomes. A more review by Reilly et al (2002) concluded that obese children are more likely to experience psychological or psychiatric problems than non-obese children, and girls are at greater risk than boys. In particular, low self-esteem and behavioural problems were associated with obesity (Reilly *et al.,* 2002). Peer group rejection and social exclusion or isolation is common for obese children (Reilly *et al.,* 2002). Cultural messages regarding obesity become internalised by adolescents and may produce a lasting distorted self-image. In the US social rejection of overweight adolescents is reflected in lower college acceptance rates, lower marriage rates and compromised economic attainment in young adults (Must, 1996).

An overweight child has a high risk of becoming an overweight adult (Whitaker *et al.*, 1997). Obesity tracks from childhood into adulthood, and the relative risk of an obese 10-13 year old becoming an obese adult is six to seven times greater than that of his/her non-obese peers (Epstein *et al.,* 1996). The chances of obesity persisting increase with obesity severity (Reilly *et al.*, 2002). The evidence of tracking of obesity from childhood into adulthood adds to the importance of preventing the development of obesity early in childhood (Dietz, 1998).

In addition, obesity in adolescence is associated with an increased morbidity and mortality in adulthood, which was shown after a 50-year follow-up, and demonstrated to be independent of adult body weight (Must *et al.*, 1992). This has led to an increased recognition of the importance of childhood as a focus for obesity prevention programmes (Whitaker *et al.*, 1998).

1.5. Prevalence Of Childhood Obesity In The UK

The increase in obesity has not been confined exclusively to adults. Overweight and obesity are now more common than expected in children (WHO 1997; Reilly *et al.*, 1999; Chinn and Rona 2001; Ogden *et al.*, 2002; Heude *et al.*, 2003; Hedley *et al.*, 2004). There is clear evidence that British children and even pre-school children have been getting fatter (Parsons *et al.*, 1999; Reilly *et al.*, 1999). From 1989 to 1998, there was a 60% increase in the prevalence of "overweight" (BMI >85th centile) and 70% increase in the prevalence of obesity (BMI >95th centile) among 3 to 4 year old English children in the Wirral (Bundred *et al.*, 2001) for example.

A study published by Reilly and Dorosty (1999) showed an excess of "overweight" and obesity is present in English children even before the age of school entry in 1996 (Figure 1.1). The data were consistent with evidence of an epidemic of adult obesity and support the view that efforts to prevent obesity should begin early in childhood (Reilly and Dorosty, 1999).

Data from a nationally representative sample of 2630 English children in 1996 showed that the frequency of "overweight" (i.e. BMI >85th centile relative to the UK; Cole *et al.*, 1995) ranged from 22% at age 6 years to 31% at 15 years and that of obesity (i.e. BMI >95th centile relative to the UK reference; Cole *et al.*, 1995) ranged from 10% aged 6 years to 17% at 15 years (Reilly and Dorosty, 1999).

The Quality Improvement Scotland Report (2003) showed that in Scottish children (born between 1995 and 1998), were 21.3% overweight (i.e. BMI's >85th but <95th centile relative to the UK reference data; Cole *et al.,* 1995). 8.8% obese (i.e. BMI's >95th centile relative to the UK reference data of 5%; Cole *et al.,* 1995) and by 3.5 years of age 4.5% were severely obese (i.e. BMI's >98th centile relative to the UK reference data of 2%; Cole *et al.,* 1995).

At all ages, the percentages of Scottish children who were estimated to be overweight, obese and severely obese were higher than expected, with approximately 10% obese at primary school entry age in 2001, and 20% on leaving primary school (BMI >95th centile relative to the UK reference data; Cole *et al.,* 1995). These data, when taken along with the evidence of an epidemic of adult obesity, support the view that efforts to prevent obesity should begin in early childhood (Reilly and Dorosty, 1999).

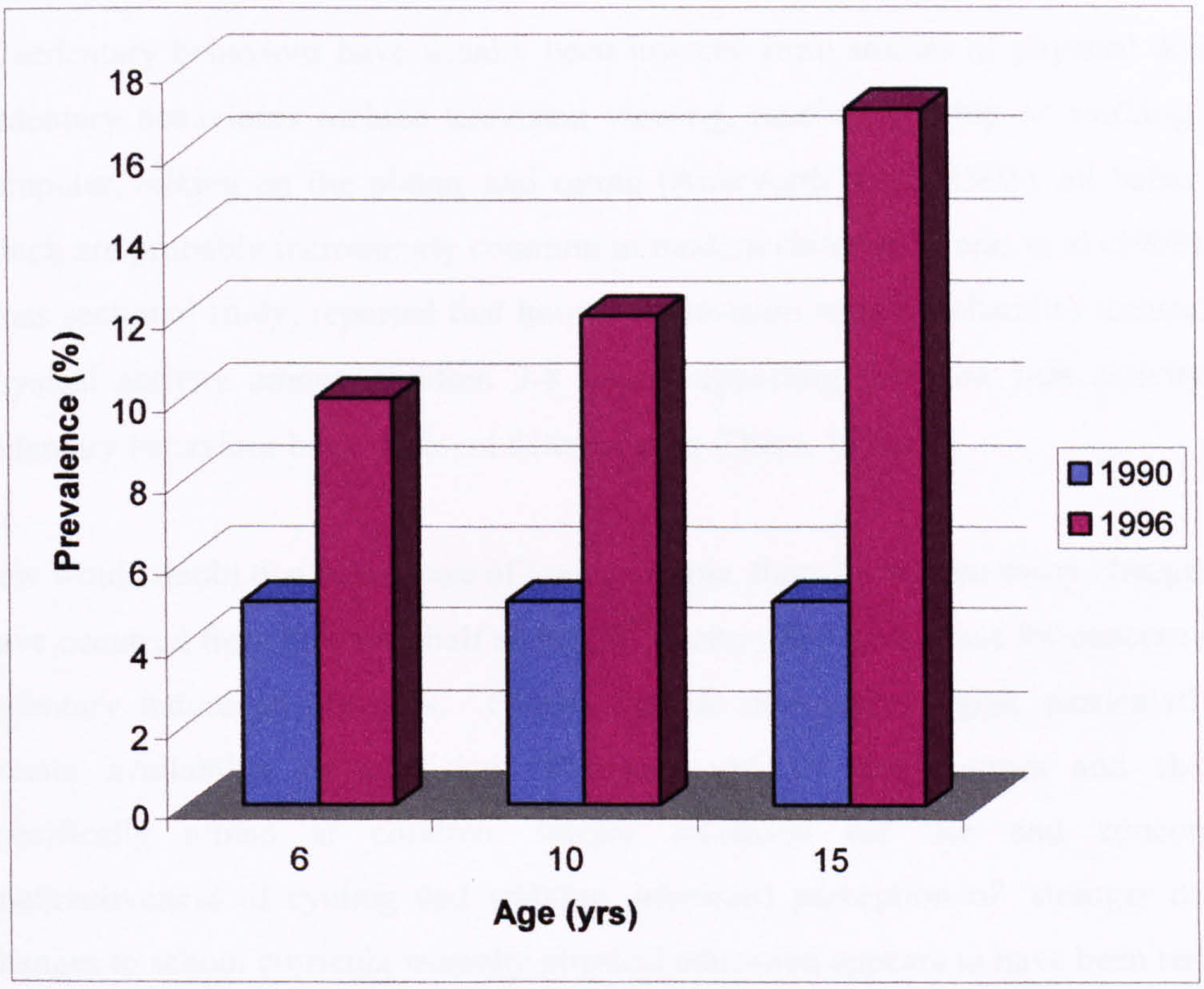
1.6. Obesity And Physical Activity In Children

While the prevalence of obesity has been increasing in the developing world, the levels of physical activity have probably declined (Troiano *et al.*, 1998; Parsons *et al.*, 1999; Reilly *et al.*, 1999). The United States is among those countries in which, despite a dramatic increase in the prevalence of obesity, there is no good evidence for any appreciable change in energy intake over the last decade. In fact, there may have been some fall in energy intake (Bouchard, 2000). The National Food Survey data (Gergory *et al.,* 2000) indicated that average energy intakes have fallen by about 20% since 1970, while the prevalence of obesity has doubled.

Data for the National Food Survey were collected using food questionnaires. The limitations of food questionnaires such as under-reporting and/or over-reporting have been well documented so the conclusion of a decrease in energy take must be viewed with caution (Melanson *et al.,* 1996). However, some supporting evidence suggests that a reduction in physical activity in children (Troiano *et al.*, 1998; Reilly *et al.*, 1999) and adults is the most important determinant of being overweight.

It is not difficult to see that major changes in lifestyle have occurred in youngsters over the last few decades that lead to reduction in physical activity levels (Jebb, 1997). Trend data collected by the Department of Transport demonstrates that, in the UK between 1985 and 1992, walking and cycling by children decreased substantially (Di Guiseppi *et al.*, 1997). During the same period, the average distance walked in a year by children ages <14 years declined by 20% and distance cycled fell by 26%. In contrast, between 1985 and 1992 the average distance children travelled in a car in a year increased by 40% (Pullinger, 1998).

Figure 1.1. Obesity Epidemic in English Children: Cross-sectional study in 1990 & 1996 of Obesity (BMI≥95th centile)



(Courtesy of Reilly and Dorosty: Epidemic of obesity in UK Children, 1999)

1.7. Sedentary Behaviour

Sedentary behaviour is defined as a state in which bodily movement is minimal representing a state where energy expenditure approximates resting metabolic rate (Dietz, 1996). Recent evidence suggests that sedentary behaviour should be viewed as a separate construct from physical activity (Reilly *et al.,* 2004) with different determinants than physical activity (Gordon-Larsen, 2000). The measurement of sedentary behaviour may potentially be very useful for many clinical and public health applications, and in particular for the treatment and prevention of childhood and adolescent obesity (Reilly *et al.,* 2004). While efforts have been made to quantify activity and the effects of physical activity on morbidity and mortality, so far the quantification of sedentary behaviour has received far less attention (Dietz, 1996).

Because sedentary behaviour has not been viewed as a separate construct the effects of sedentary behaviour have usually been inferred from studies of physical activity. Sedentary behaviours include television viewing, reading, playing or working on a computer, talking on the phone, and eating (Ainsworth *et al.,* 1993), all behaviours which are probably increasingly common in modern children. Toras et al (1989), in a cross sectional study, reported that hours of television were unrelated to measures of physical activity among children 3-8 years supporting the view that activity and sedentary behaviour have different determinants (Dietz, 1996).

Few would doubt that in the case of young people, there have been many changes that have occurred from the latter half of the 20th century that give cause for concern about sedentary nature of lifestyles. Factors include new technologies, particularly the greater availability of television (TV) sets and TV programmes and channels specifically aimed at children, hugely increased car use and concomitant unattractiveness of cycling and walking, increased perception of 'stranger danger' changes to school curricula whereby physical education appears to have been reduced, and other competing demands on young peoples time. For these reasons it is widely thought a greater understanding of sedentary behaviour in young children is necessary as levels of childhood obesity rise and levels of physical activity may decline possibly due to a wide array of tempting sedentary pursuits available (Biddle *et al.,* 2004).

Epstein et al (2000) has tested the effect of decreasing sedentary behaviours in treating paediatric obesity. The object of their study was to compare the influence of targeting sedentary behaviours versus increasing physical activity and decreasing sedentary behaviour in ninety obese 8 to 12 year olds. The result supports decreasing sedentary behaviour (such as watching television, playing computer games, watching videos) as an adjunct in the treatment of obesity (Epstein *et al.,* 2002).

Few analyses have been designed to examine whether sedentary behaviour and physical activity exert independent effects on health outcomes. Obesity represents an exception. One sedentary behaviour that has received considerable research attention is television viewing. Television viewing has been reported to be associated with obesity, resting energy expenditure, and lower daily physical activity among children and adolescents (DuRant *et al.,* 1994). It has been widely reported that American children spend more time watching television and videotapes and playing video games than doing anything else except sleeping (Dietz and Gortmaker 1985; Durant, 1994; Gortmaker *et al.,* 1996; Robertson, 1999; Faith *et al.*, 2001; Janz *et al.,* 2002).

However, some epidemiological studies have found weak inverse associations between hours of television viewing and physical activity (Durant *et al.*, 1994; Robinson *et al.*, 1999). In a recent nationally representative cross-sectional survey in the US, 4063 children ages 8-16 years were examined as part of the National Health and Nutrition examination survey III, it was found that many US children watched a great deal of television (67% $\leq$ 2hrs per day, 26% $\geq$ 4hrs per day). Andersen et al (1998) found that skinfold thickness increased in both boys and girls as the amount of television viewing increased. This finding was consistent with an earlier study by Dietz and Gortmaker (1985) who also found a significant relationship between television viewing and the prevalence of obesity in children and with evidence from prevention studies where the focus was on a reduction in television viewing (Robertson *et al.*, 1993).

A longitudinal US analysis of nationally representative data from cycles 2 and 3 of NHANES (1967 to 1970) indicated that television viewing was strongly related to the onset of new cases of obesity and to the lack of remission among obese children (Dietz *et al.,* 1985).

Despite the dramatic increase in obesity among pre-pubertal children there is no apparent increase in their total energy intake. This would therefore suggest that the increased prevalence of obesity was in part the result of increased leisure time spent in sedentary behaviour (Gortmaker *et al.,* 1996).

It has been recently found that reducing television, videotape and video games use might be a promising, population-based approach to prevent childhood obesity (Robinson, 1999). Gortmaker et al (1996) in an observational study examined the relationship between hours of television viewing and the prevalence of overweight in 1990, and the incidence and remission of overweight from 1986 to 1990 in a nationally representative sample of 746 children aged 10-15 years. Overweight was defined as a BMI greater than the 85^{th} percentile for age and gender. Results showed a strong dose-response relationship between the prevalence of overweight in 1990 and hours of television viewed. Gortmaker et al (1996) concluded that television viewing affects weight, and reductions in viewing time could help prevent this increasingly common chronic health condition. In addition, the trends in television viewing in children show an enormous increase, leading to an increase in sedentary/inactive behaviours in the US (Epstein *et al.*, 2000).

Recent research conducted by Biddle and colleagues challenge the conventional belief that sedentary behaviour is correlated with body fatness in modern children. TV viewing habits of young people explained less than 1% in the variance in their body fatness (Biddle *et al.,* 2003). Furthermore, Biddle and colleagues concluded that the majority of children and youth are not 'high' users of TV and argue that motorised transport (i.e. cars, buses etc) has reduced physical activity more than TV viewing (Biddle *et al.,* 2003).

1.8. Physical Activity In Childhood

Until recently little is known about the current physical activity levels of young children (Kohl *et al.*, 1998; Sallis *et al.*, 2000; Livingstone *et al.*, 2003). Most existing data have been obtained from older children/adolescents, or from studies before the obesity epidemic. It has been argued that young children and pre-school children's physical activity is typically performed in short bursts instead of sustained periods of movement (Bailey *et al.*, 1995; Pelligrini *et al.*, 1998); activity patterns are intermittent in nature. Young children are spontaneously active with frequent bouts of brief physical activity with rapid transitions from high and low intensity physical activity. This physical activity is obtained through exercise play, rough and tumbles play, pretend play and imaginary play (Pelligrini *et al.*, 1998).

Play is the most natural way for young children to be active (Riddoch *et al.*, 1995). There is concern that the activity in youngsters gradually declines through the adolescent years as children are habituated to sedentary living (Riddoch *et al.*, 1995). The adult lifestyle (which probably directly influences the child) is organised in such a way as to reduce physical activity (Riddoch *et al.*, 1995). Houses contain appliances to 'make our lives easier', thus reducing our activity levels and encouraging sedentary behaviour. Children are increasingly kept indoors, at school and at home to do homework, television programmes are produced to capture their attention and as the number of hours spent watching television has increased (Durant *et al.*, 1994; Gortmaker *et al.*, 1996; Reilly *et al.*, 1999) the activity level of children has decreased and the level of sedentary behaviour has probably increased (Reilly *et al.*, 2004).

Sallis et al (2000) in an extensive review of correlates of physical activity levels in children evaluated 102 published studies. Fifty-four published studies in children aged 3 to 12 years were reviewed. Unfortunately there were very little data on pre-school aged children. Over 80% of the studies were conducted in the US. Five of the twelve studies found that boys were more active than girls even at pre-school age and time spent outdoors resulted in higher than average activity levels (Pate *et al.*, 1995). Trost et al (2002) also reported a rapid decline in physical activity during childhood and adolescence.

Furthermore Gavarry et al (2003) while investigating habitual physical activity during school time and free time in 82 children using heart rate and questionnaires to assess physical activity concluded that children, irrespective of gender, were more sedentary during free days than during school presumably because they spend more time engaging in sedentary behaviours on free days. Sleap and Warburton (1996) observed that free time periods at school were associated with more intense physical activity than free time periods out of school (evenings, weekends and holidays) in English 5-11 year olds. However, no differences in habitual physical activity between weekdays and weekend have been observed in other samples of European pre-schoolers and primary one school children (Jackson *et al.,* 2003).

A few studies have reported seasonal differences in activity levels. Fulton et al (2001) found that sedentary behaviour was higher in winter than summer. In a review by Sallis et al (2000) variables that were consistently statistically and positively associated with children's physical activity were sex (male), parental overweight status, physical activity preferences, intention to be active, perceived barriers (inverse), previous physical activity, healthy diet, programme/facilities access, and time spent outdoors. Sallis et al (2000) suggested that additional studies were needed to confirm the findings and explore additional factors that may influence a child's activity behaviour. While investigating the factors associated with physical activity in young children, Finn at el (2002) found that sex, history of pre-term birth, child care centre, and father's BMI were the biggest influences on the daily physical activity of young children. The childcare centre was the strongest predictor of activity levels. This finding was in line with the finding of Pate et al (2004) who investigated demographic factors, which might be associated with physical activity in 281 US preschool children using the MTI/CSA accelerometer.

1.9. Adiposity Rebound

Several sources of data suggest that the time of adiposity rebound (AR) may represent a critical period for the development of obesity (Whitaker *et al.,* 1997; Whitaker *et al.,* 1998). The body mass index increases in the first year of life and subsequently decreases (Dietz, 1994). BMI starts to increase again at about 4-7 years. The point of maximal leanness or minimal BMI has been called the adiposity rebound (AR) (Rolland-Cachera *et al.*, 1984; Dorosty *et al.,* 2000). An early AR (young age at onset of AR) is associated with a higher BMI in adolescence and young adulthood (Rolland-Cachera *et al.,* 1984; Whitaker *et al.,* 1998).

A number of possible mechanisms of early AR have been proposed. These include an early AR associated with a high protein intake (Rolland-Cachera *et al.,* 1995). However, there is in fact no clear evidence that any dietary variables are related to timing of the AR (Dorosty *et al.,* 2000). Rolland-Cachera et al (1984) suggested that an early AR might constitute a marker for generalised growth acceleration and cell hyperplasia (Whitaker *et al.,* 1998). They showed that early AR was associated with advanced bone age and suggested that the acceleration in skeletal maturation was a marker for fat cell hyperplasia. However, there has been no study as yet showing that the adipose tissue of children with early AR is more hyperplastic than adipose tissue of children with late AR. The age of AR may be genetically programmed. It would therefore be difficult to alter and would merely be a reflection of an inherited susceptibility to obesity (Whitaker *et al.,* 1998).

It has been suggested that parental BMI is a significant factor associated with timing of the AR. Children of parents with a high BMI, or with at least one obese parent, are significantly more likely to have an earlier AR (Dorosty *et al.*, 2000; Whitaker *et al.,* 1998). Alternatively, the age at AR also could reflect important socio-economic factors tween socio-economic status and timing of AR. This is important given the recent concern over the interrelationship between socio-economic position and obesity.

At present the factors that influence the timing of the AR are unclear (Whitaker *et al.*, 1998). However, there is a secular trend to an earlier age at AR which implies that there is a strong environmental influence (Reilly *et al.*, 2001). An understanding of the factors which influence the timing of the AR might facilitate obesity prevention (Dorosty *et al.*, 2000) and will require better understanding of the factors which influence energy balance in pre-school children. Since dietary factors seem unlikely to have a major influence on the timing of AR (Dorosty *et al.*, 2000), and since there is a strong secular trend to earlier AR, it is likely that physical activity and/or sedentary behaviour might be important, which is a further argument for research aimed at understanding physical activity and sedentary behaviour in young (pre-school) children. One major limitation in this area has been difficulty in measuring physical activity and sedentary behaviour in young children.

1.10. Methods For Assessment Of Physical Activity And Sedentary Behaviour In Young Children

Accurate assessment of physical activity in free-living subjects presents researchers with a formidable challenge. In approaching the topic, it is always important to remember that physical activity and energy expenditure are not necessarily synonymous (Bouchard, 2000). For example, a short burst of intense exercise may produce the same energy expenditure as a much longer burst of less intense exercise (Montoye *et al.*, 1996). Some of the techniques reviewed in this chapter measure the amount and/or patterns of physical activity (e.g. accelerometers); others only measure energy expended in physical activity (e.g. doubly labelled water). Table 2.1 (appendix) provides a summary of the various methods used to assess physical activity and energy expenditure.

The amount of physical activity performed by free-living subjects has been expressed in time spent in physical activity (hours, minutes), in units of movement (counts), or as numerical scores derived from responses to a questionnaire. Physical activity has also often been expressed as energy expended. The amount of energy expended in physical activity has been expressed as total energy (kJ), work performed (watts), and metabolic equivalents (METs). One MET is equal to the resting oxygen consumption, and for non-obese adults is approximately $3.5 ml \cdot kg^{-1} \cdot min^{-1}$ of oxygen, or 1 kcal·kg bodyweight^{-1} $\cdot h^{-1}$. The MET provides a way of expressing the energy cost of activities as multiples of resting metabolic rate (RMR). Ainsworth et al (1993) has provided an up to date compendium of MET values for adults, and a paediatric compendium is currently being developed.

Numerous methods for measuring/assessing physical activity have been used in research studies, and all have their strengths and weaknesses (LaPorte *et al.,* 1985). The major techniques for assessing physical activity levels and energy expenditure in physical activity can be divided into three categories: (a) criterion methods also known as reference or laboratory methods; (b) objective methods and; (c) subjective methods.

The methods selected to measure physical activity and sedentary behaviour in epidemiological studies needs to be valid (extent to which a method measures what it is designed to measure (Bland, 2000) and reliable (constantly provides the same results under the same conditions (Bland, 2000). Therefore, the primary aim of this chapter was to review all the methods that have been commonly used to measure physical activity in children in the above three categories. The review was then used to identify the most appropriate criterion method and identify the most appropriate accelerometers for use in the studies described in this thesis.

1.11 Criterion Methods For Measuring Physical Activity

For the purpose of this review of methods of assessing physical activity, direct observation, doubly labelled water (DLW) and other forms of direct and indirect calorimetry are considered the criterion methods for assessment of physical activity in children and adolescents (Melanson *et al.,* 1996; Johnson *et al.,* 1998; Welk *et al.,* 2000a; Ekelund *et al.,* 2001). DLW is well recognised as a criterion measure or "GOLD STANDARD" for field evaluations of energy expenditure (EE). This technique assesses total caloric expenditure by estimating carbon dioxide production using isotope dilution during a minimum of 7 days. EE is a physiologic consequence of physical activity and is directly linked to health and disease prevention. Thus, DLW and indirect calorimetry can be used as criterion measures for physical activity assessment (Welk *et al.,* 2000). However, it should be noted that EE and physical activity are distinct constructs, which may limit attempts to validate physical activity measures against EE. Direct observation is a more practical and comprehensive criterion measure for physical activity research (Welk *et al.,* 2000).

1.11.1. Doubly Labelled Water

With this method, a dose of (non-radioactive), stable isotope label ($^2H_2{}^{18}O$) is administered orally and the oxygen atoms in expired CO_2 equilibrate with the oxygen atoms in the body water. Over the next 5 to 14 days, ^2H is eliminated as water; while ^{18}O will be eliminated as water and CO_2.The difference between the elimination rates is proportional to CO_2 production (i.e. EE) (Schoeller *et al.,* 1986; Westerterp, 1999a). The DLW method has been validated against whole room calorimetry in adults (Schoeller *et al.,* 1986) and with periodic respiratory gas exchange in infants (Jones *et al.,* 1987; Johnson *et al.,* 1998). Similar research with children was not found, probably because of the difficulty in obtaining consent from children and their parents for multiple days of calorimeter confinement.

The DLW technique has several advantages for evaluating EE and activity energy expenditure (AEE) (Table 2.2). It can be easily used in free living (normal daily life) participants, has low reactivity and is accurate to within 3 to 4% of calorimeter values in adults (Schoeller *et al.,* 1986; Murgatroyd *et al.,* 1993). Unfortunately, DLW also has several limitations worth noting (Schoeller *et al.,* 1986; Murgatroyd *et al.,* 1993). The ^{18}O isotope has been difficult to obtain, as it is very expensive. Hence DLW is not suitable for studies of large numbers of subjects. Secondly, measurements must be taken over at least a 7-day period (Murgatroyd *et al.,* 1993; Sirard and Pate, 2001) and only TEE can be obtained. Therefore, daily or hourly patterns of EE cannot be investigated. Finally, while TEE is critical, it may be equally important to evaluate other parameters associated with physical activity such as the duration, intensity and frequency of moderate-to-vigorous physical activity (MVPA), vigorous physical activity (VPA), or sedentary behaviour. Detailed information on daily changes in physical activity and sedentary behaviour are missing when DLW is used.

Table 1.2 Advantages and Disadvantages of the Doubly Labelled Water Method

Advantages	Disadvantages
Validity for estimating energy expenditure in laboratory appears to be good, accurate to about 1-3% with a precision of about 4-7%. Accuracy under the right conditions in the field would probably also be good.	The considerable cost of ^{18}O has been compounded by limited availability and limits the application to relatively small groups.
Method is equally applicable to children and adults.	Analysis of the samples is costly and expensive, a mass spectrometer as well as expertise to operate the equipment is required.
Energy expenditure is measured over a relatively long period.	Total energy expenditure over 7-21 days approx. is measured, so no knowledge is obtained for brief periods of peak expenditure. Likewise, no information about specific activities is available.
In the measurement of energy expenditure, a measure of body composition also becomes available.	In field studies, because carbon dioxide production and not oxygen utilisation is being measured, some error is introduced if the respiratory quotient is not known.
The method is safe and painless and doesn't encumber the subjects during rest or activity. It is also less likely to influence the subject to alter activities than is true of some other measure. Method is equally applicable to children and adults.	Does not give information on daily patterns of physical activity, AEE must be inferred from TEE.

Note: Adapted from Montoye et al., 1996, Table 3.2

1.11.12. Other Forms Of Indirect Calorimetry

Open-circuit indirect calorimetry measures EE from O_2 consumption and CO_2 production. Indirect calorimetry during rest and exercise is used extensively and considered an accurate and valid measure of short term EE. However, using indirect calorimetry to measure physical activity is difficult because of the non-portable gas analysis equipment required. Therefore, this method is impractical for validating a survey that measures 'usual' or weekly physical activity. Indirect calorimetry has been used, however, to validate heart rate monitors (Bitzar *et al.*, 1996; Treuth *et al.*, 1998), pedometers (Eston *et al.*, 1998) and accelerometers (Melanson and Freedson, 1995; Eston *et al.*, 1998; Trost *et al.*, 1998; Westerterp, 1999b; Nichols *et al.*, 2000; Puyau *et al.*, 2002; Eisenmann *et al.*, 2004) in laboratory settings (Murgatroyd *et al*, 1993). Manufacturers have introduced portable, lightweight metabolic systems that should improve the estimates of EE during physical activities under more natural settings. Despite this advance, at present the equipment is still too cumbersome to use under long-term free-living conditions, especially in young children. To date there are no within-person reliability estimates using the indirect calorimetry method in preschool children (Fulton *et al.*, 2001). However, indirect calorimetry has not been recommended for use in preschool children because of the high cost of conducting the research and the high burden for participants and staff (Fulton *et al.*, 2001).

1.11.13. Direct Observation

Direct observation (DO) is one of the easiest, most practical and appropriate criterion reference methods employed to assess physical activity involves an observer recording observations while watching a subject (Fairweather *et al.*, 1999; Finn and Specker, 2000; Welk *et al.*, 2000; Fulton *et al.*, 2001; Sirard and Pate, 2001). While considerable time and effort are required to conduct direct observation studies, the detail provided can be a highly useful tool for characterising the different dimensions of young children's physical activity e.g. type, mode, intensity, and duration (Melanson *et al.*, 1996; Welk *et al.*, 2000).

This technique has frequently been used to study school children and pre-school children when other methods were not feasible (Montoye *et al.*, 1996). Direct observation has been regarded by some researchers as one of the best criterion measures to validate other assessment tools (Welk *et al.*, 2000).

As previously mentioned direct observation is probably the most practical and appropriate criterion measure of physical activity and patterns of physical activity for young children (Sirard and Pate, 2001). The direct observation technique is ideal when behaviour is the main focus of concern. It can allow for several different dimensions of activity (e.g. type intensity and duration) to be simultaneously recorded (O'Hara *et al.*, 1989; Melanson *et al.*, 1996).

For most accurate recording, the sampling interval employed should be sensitive to brief periods of activity and not exclude short bursts of activity. This is a major concern when measuring children, where activity patterns are believed to be constantly changing (Klesges *et al.*, 1987). Welk et al (2000) noted that as a method for assessing physical activity direct observation was highly suited for studies involving children, but because it is highly labour intensive its greatest value probably lies in the validation of other methods of physical activity assessments, such as accelerometry.

The observational method would also appear to be to be sufficient when the observation period is short e.g. during a physical activity class (O'Hara *et al.*, 1989). The observational method is not limited by recall or self-reporting biases that can occur in questionnaires or activity diaries. Evidence supporting the use of the direct observation method is available from studies comparing direct observation scores with heart rate (O'Hara *et al.*, 1989) or oxygen consumption (Puhl *et al.*, 1990).

Validity of direct observational methods is high with correlations ranging from r= 0.61 to 0.91 (O'Hara *et al.*, 1989) and heart rate and oxygen consumption were significantly different among the observed physical activity levels categorised by the direct observation method (Puhl *et al.*, 1990; Bailey *et al.*, 1995).

Direct observation as a method for assessing physical activity has a number of limitations. The system can be costly to implement because of its labour intensiveness. Observers are expensive to recruit and train and multiple observers are needed to assess a number of children reliably (O'Hara *et al.*, 1989). However, possibly the greatest limitation is the presence of the observer. If the observed subject is aware of the observer their behaviour may be modified. Fortunately, available studies have demonstrated that most observed children ignore the observers after a few minutes (Puhl *et al.*, 1990). Because observation is time consuming and expensive it is really only suited for relatively small groups. Also, observations are confined to relatively short periods and may not, therefore, reflect habitual physical activity accurately. Video recording of sessions can provide material, which can be used to improve training as well as check the reliability and reproducibility of the activity assessments (Montoye *et al.*, 1996).

Overall, doubly labelled water, indirect calorimetry and direct observation are frequently used as criterion methods to validate other physical activity measures such as motion sensors (chapter 3), questionnaires and heart rate monitors. Direct observational techniques for assessing physical activity are valuable tools and have been widely used as a criterion method to validate other field assessment techniques (Baranowski *et al.*, 1984).

1.12. Objective Techniques

Consistent with the definition that physical activity is bodily movement, which produces energy expenditure above basal level, motion sensors (i.e. pedometers and accelerometers) can be used to detect body movement and hence provide an estimate of physical activity. Advancements in technology have increased the sophistication, sensitivity and accuracy of these instruments (Sirard and Pate, 2001).

1.12.1. Pedometers

The simplest forms of motion sensor are pedometer, which are used to calculate distance walked, or the number of steps taken over a period of time (Montoye *et al.*, 1996). They contain a horizontal spring suspended level arm, which moves up and down in response to the vertical acceleration of the body during locomotion. With each step, the lever arm makes mechanical contact and one step is recorded. Output for the pedometer is *total steps* (Bassett *et al.,* 1996).

Pedometers have the advantage of being relatively inexpensive, re-useable, and objective (Bassett *et al.,* 1996). The units themselves are small, thus offering a possible non-reactive and objective measure of activity. Pedometers posses' similar benefits and weakness to other motion sensors such as insensitivity to non-locomotor forms of movement but, in addition, have even lower accuracy and precision (Welk *et al.,* 2000b; Trost, 2001).

In addition to this limitation, pedometers do not have time sampling capabilities, they cannot provide detail on frequency or intensity of physical activity, nor do they usually posses real-time data storage capabilities (Trost, 2001). Furthermore, pedometers underestimate step frequency at slow walking speeds due to the inability of the instrument to capture the vertical acceleration at low speeds (Montoye *et al.*, 1996). Pedometers, cannot easily account for changes that may occur in stride length. As a consequence at fast walking pace pedometers underestimate total distance walked, probably due to increased stride length at the faster speeds (Montoye *et al.*,

1996). Moreover, pedometers are not sensitive to sedentary behavior, isometric exercise, or activity that involves the upper limbs (Montoye *et al.,* 1996).
Also due to the differences in spring tension of the lever arm, inter-instrument variability is very high (Montoye *et al.,* 1996). Floor and ceiling effects may also lead to inaccuracies and contribute to poor inter and intra-instrument variability (Montoye *et al.,* 1996). Many commercially available pedometers provide users with estimates of EE. Unfortunately the algorithms used for these calculations are not appropriate for children. These limitations make the pedometer less suitable for research measurements of habitual physical activity in young children (Montoye *et al.,* 1996; Sirard and Pate, 2001; Trost, 2001).

1.12.2. Accelerometers

Children's patterns of physical activity have traditionally been assessed by direct observation, questionnaires, and heart rate monitoring (Puyau *et al.*, 2001). Activity monitors have been developed in response to the lack of reliability of self-report measures, and the complexity of heart rate monitoring. Accelerometers measure accelerations caused by bodily movement in one (uniaxial), two (biaxial) or three (triaxial) planes of motion. A number of accelerometers, varying in size, cost and weight are commercially available such as the Caltrac, MTI/CSA Actigraph (uniaxial), Actiwatch and Actical (biaxial), Tritrac and RT3 (triaxial).

Accelerometers are more sophisticated electronic devices (than the previously mentioned pedometers) and measure accelerations produced by body movement. In contrast to the spring mechanisms of pedometers, accelerometers use piezoelectric transducers and micro processing that convert recorded accelerations to a quantifiable digital signal referred to as counts (chapter 3). With the development of small accelerometer based activity monitors, the ability to monitor children's activity has improved greatly. Recent advances in integrated circuitry and memory capacity have produced sensitive, unobtrusive, accelerometer based devices that measure continuously the intensity, frequency, and duration of movement for extended periods (Sirard and Pate 2001).

1.12.3. The MTI/CSA Accelerometer

The theoretical basis underlying the use of the uniaxial accelerometer (MTI/CSA Accelerometer) to assess physical activity is based on the assumption that accelerations of the torso closely reflect energy cost of movement (Melanson and Freedson, 1996; Montoye *et al.,* 1996). The Computer Science and Applications (MTI/CSA) activity monitor (Model WAM 7164) is a small (5.08 x 4.06 x 1.524cm) light (42.5g) *uniaxial* accelerometer, which is encased in a plastic case (www.Mtiactigraph.com) which detects bodily acceleration in the vertical (Z) direction.

The MTI/CSA accelerometer is designed to measure and record time varying accelerations ranging in magnitude from 0.05 to 2G's approximately with a frequency response of 0.25 to 2.50Hz. These parameters were chosen as they best detect normal human motion and reject motion from other sources such as vibrations from vehicles (Janz, 1994; Trost *et al.,* 1998; Fairweather *et al.*, 1999; Sirard *et al.,* 2000; Trost *et al.,* 2000; Janz *et al.,* 2004).

The acceleration signal is filtered and digitised by an 8 bit analogue to digital converter (A/D) and the magnitude is summed over a user specified interval of time (epoch), and at the end of each epoch the activity count is stored internally and the accumulator is reset to zero. Epochs ranging in length from 1s to several minutes have been used (Fairweather *et al*, 1999; Welk *et al.,* 2004).

This facility to vary epoch length provides an opportunity to examine the frequency, duration and intensity of exercise. The hardware used in the MTI/CSA (model 7164) includes an 8-bit micro-controller with an 8-bit analogue to digital converter, 64 kilobytes of non-volatile RAM, a low powered operational amplifier, and a piezoelectric motion sensor with analogue signal conditioners and filters. Power is supplied by a 2430 coin cell lithium battery, which has a battery life in excess of 4,000 hours.

Communications with the MTI/CSA activity monitor is achieved with a coded infrared beam of light via a Reader Interface Unit (RIU) connected to a serial port. Smart terminal emulation software is supplied with the RIU to support PC communication with the activity monitor (MTI/CSA 1995).

The accelerometer can be worn on the wrist, ankle or the waist (MTI/CSA 1995). The MTI/CSA when worn at the ankle is also placed with the notch pointing upward. The placement of the MTI/CSA on the right hip above the iliac crest is now recognised as being standard practice (Nilsson *et al.,* 2002; Puyau *et al.,* 2002). Throughout the studies described in this thesis the MTI/CSA was consistently worn snugly on the right hip with the notch pointing upwards in accordance with current research (Fairweather *et al.,* 1999; Nilson *et al.,* 2002; Puyau *et al.,* 2002; Jackson *et al.,* 2003; Montgomery *et al.,* 2004; Reilly *et al.,* 2004). The MTI/CSA's were secured firmly around the waist using an elastic strap, the orientation and placement of the MTI/CSA accelerometers were held constant from day to day as to avoid variability.

Studies have shown the MTI/CSA accelerometer to be reliable for measurement of physical activity. Melanson and Freedson (1996) assessed the test reliability (r=0.90-0.99) of the MTI/CSA accelerometer worn on the waist, ankle and wrist by collecting MTI/CSA accelerometer recordings during treadmill walking and jogging on two separate occasions in a group of healthy adults. High correlation coefficients, ranging from 0.93 to 0.99 between MTI/CSA accelerometer recordings collected during repeat testing were reported in this study. Fairweather et al (1999) tested inter-instrument reliability of the MTI/CSA accelerometer by attaching the MTI/CSA accelerometer to a mechanical shaker device, which simulated body movement. A minimal difference (<3%) was observed between MTI/CSA accelerometers attached to the shaker.

Traditionally, epidemiological studies have relied on questionnaires to quantify the amount and intensity of physical activity that participants perform (Montoye *et al.,* 1996). These methods have served epidemiology well, but they are subject to limitations (Laporte *et al.,* 1985). Therefore, the challenge remains to develop accurate, objective methods of measuring physical activity within large populations. Uniaxial accelerometers have the potential to provide an accurate and objective estimate of physical activity in epidemiological studies.

However, to date, relatively few studies have examined the validity of accelerometers. Melanson and Freedson (1995) demonstrated the MTI/CSA monitor to be a valid measure of treadmill walking and running in 15 adult males and 13 adult females (aged 12.0 ± 1.0yrs and 21.0 ± 1.1yrs respectively) using energy expenditure assessed via indirect calorimetry as the criterion measure (Melanson and Freedson 1995). Sirard *et al.*, (2000) evaluated the MTI/CSA activity monitor while quantifying physical activity in 19 free-living subjects (means age 25 yrs ±3.6yrs) using an activity diary as the comparative measure. King et al (2004) evaluated the validity of the MTI/CSA and four other accelerometers against indirect calorimetry in 22 adults (mean age 24.7 ± 5.4yrs for females and males 25.2 ± 4.5 yrs). The researchers concluded that MTI/CSA monitoring might be useful in field situations where total physical activity and patterns of physical activity are the desired outcome.

The MTI/CSA accelerometer is also practical for use in pre-school children as it is objective, lightweight and not easily tampered with (Reilly *et al*, 1999; Jackson *et al.*, 2003). MTI/CSA accelerometers have been validated in children against heart rate monitoring (Chu *et al.*, 2003), direct observation of activity (Klesges *et al.*, 1987, Puhl, 1990; Fairweather *et al.*, 1999; Puyau *et al.*, 2002; Kelly *et al.*, 2004) energy expenditure using direct and indirect calorimetry (Trost *et al.*, 1998; Chu *et al.*, 2003; Eisenmann *et al.*, 2004) and doubly labelled water (Ekelund *et al.*, 2001).

Janz (1994) assessed the validity of an older version of the MTI/CSA model, the WAM 7164 monitor, as a field measure of physical activity in thirty-one children aged 7 to 15 who wore the belt for 12 hours per day for three consecutive days using heart rate telemetry as the comparative measure. Correlation coefficients between MTI/CSA counts pre minute (cpm) and various indices of heart rate, including average net heart rate and number of minutes with heart rate greater than or equal to 150 beats·min^{-1}, were statistically significant and ranged from 0.50 to 0.74 (Janz, 1994).

Janz (1994) concluded that the moderate to high correlations and the subjects' favourable response to wearing the accelerometer supported its validity and utility as an objective method for monitoring children's physical activity in a field setting. Janz (1994) did however, conclude that the between day stability of individual physical activity measures was low to moderate ($r = -0.23$ to 0.53), indicating that when using accelerometry or heart rate telemetry more than three days of monitoring is necessary to assess activity.

Trost et al (1998) evaluated the validity of the MTI/CSA monitor (model WAM 7164) as a measure of children's physical activity using energy expenditure determined by indirect calorimetry as a criterion measure. Thirty children (19 boys and 11 girls) aged 10 to 14 performed three 5 minutes-treadmill bouts, which consisted of (a) walking at 3mph, (b) walking at 4mph, and (c) jogging at 6 mph. Because previous studies have shown vertical axis accelerometers to be generally non-responsive to changes in grades, all bouts were performed at 0% grade (Melanson *et al.,* 1995).

The children also wore two MTI/CSA monitors, one on the left hip and one on the right hip. Activity counts from both MTI/CSA monitors were strongly correlated with energy expenditure ($r = 0.86$ and 0.87 $p < 0.001$), oxygen consumption ($r=0.86$, 0.87), heart rate ($r = 0.77$) and treadmill speed ($r = 0.90$, 0.89). Energy expenditure estimated from a regression equation based on counts was highly correlated with actual energy expenditure ($r = 0.62$-0.85). The data suggested that the MTI/CSA was a valid and reliable tool for quantifying treadmill walking and running in children. However, at any level of exercise intensity the variation in MTI/CSA output was wide (Trost *et al.,* 1998).

Fairweather et al (1999) validated the MTI/CSA accelerometer in 11 pre-school children (mean age 4yrs ± SD 0.4yrs) against direct observation. Direct observation was assessed using the Childrens Physical Activity Form (CPAF). Mean MTI/CSA output (cpm) were significantly positively correlated with mean CPAF score min (spm^{-1}) ($r = 0.87$, $p < 0.1$). The study suggested that using MTI/CSA could provide a reasonable summary measure of activity in pre-school children and could be used to rank the children by their by activity level.

More recently, Puyau et al (2002) validated MTI/CSA against activity energy expenditure AEE (computed as energy expenditure – resting metabolic rate) in 26 children aged 6-16yrs ($r = 0.66 \pm$ SD 0.08) and concluded that the MTI/CSA is a useful device for the assessment of physical activity in children. Although promising, accelerometers are relatively new and there remain only handful of validation studies (especially in children). Eight validation studies of the MTI/CSA accelerometer in children are summarised in table 2.3. At present, valid and meaningful translations of movement counts into energy expenditure has not yet been achieved for children (Fox *et al.*, 2000).

There are theoretical limitations to the use of accelerometers in measuring physical activity in free-living individuals (Fairweather *et al.*, 1999; Bassett *et al.*, 2000; Welk *et al.*, 2000). One well described potential limitation is the apparent inability to detect physical activity due to movements such as throwing, catching or isometric contractions such as carrying or lifting (Welk *et al.*, 2000; Swartz *et al.*, 2000). In addition, previous MTI/CSA accelerometer were not water proofed, and therefore could not be used for swimming or other water sports. There is also little reason to expect that they could be accurate for some other popular children's activities such as bicycling or in some older children activities such as weight lifting (Montoye *et al.*, 1996). Accelerometers remain fairly expensive costing several hundred pounds each (Fox *et al.*, 2000; Trost, 2001).

One of the most common approaches for field-based research is to use "cut-off points" to determine the amount of time spent in different intensity categories (Janz *et al.*, 1994). While the approach is useful, one must recognise that the cut-offs may lead to an underestimation of the activity levels in children if they are based on the number of counts recorded during a continuous bout of activity. As the accelerometer summarises the counts, the value at the end of the minute reflects the total counts within that time line. Therefore, short bursts of vigorous activity (believed to be the common pattern in young children), may become obscured by alternating periods of rest when the total value for the minute is calculated (Welk *et al.*, 2000). Averaged activity values for these minutes could lead to them being interpreted as "sedentary" time periods (Welk *et al.*, 2000).

Nilsson et al (2002) concluded that the main practical consequence of using 1-minute epochs in children is a misclassification of some vigorous activity as moderate intensity activity. Furthermore, accelerometers are unable to distinguish between different types of surfaces and changes in gradient, which could lead to an underestimation of physical activity (Montoye *et al.*, 1996; Hendleman *et al.*, 2000).

Finally a recent paper by Brage et al (2003) investigating the validity of the MTI/CSA accelerometer in a wide range of walking and running speeds in laboratory and field settings concluded the MTI/CSA no longer continued to rise linearly above approximately 9km h^{-1}. Further increments in speed did not significantly affect the MTI/CSA output; it levelled off at approximately 10,000 cpm, and showed a tendency towards a decrease at higher speeds. However, in practice this may not be a problem when conducting field experiments (especially in young children).

Despite these limitations, the MTI/CSA accelerometer has a number of advantages over other physical activity measurement techniques. Firstly, despite the theoretical disadvantage that it is uniaxial, Welk and Corbin (2000) has shown that the MTI/CSA accelerometer yielded more accurate measures of physical activity than the triaxial accelerometer the Tritrac accelerometer. Welk and Corbin (2000) also noted that accelerometers are easy to attach when compared with the heart rate monitor, it consists of only a small single unit and, unlike heart rate telemetry, and it requires no taping or strapping to the body (Janz, 1994). This advantage not only saves the investigator time but allows the subject greater freedom of movement.

Accelerometers such as the MTI/CSA have the ability to store data for long periods of time (Bassett *et al.*, 2000; Welk *et al.*, 2000) and provide an objective assessment of frequency, intensity and duration of physical activity performed (Welk *et al.*, 2000). This makes them ideal for answering questions regarding the "pattern" of physical activity, which cannot be determined from a global measure of energy expenditure, such as doubly-labelled water (Bassett *et al.*, 2000).

In addition, the MTI/CSA's small size and unobtrusive nature give them an advantage over other accelerometer and other direct methods of assessing physical activity, such as indirect calorimetry (Bassett *et al.*, 2000), which also make them suitable for large scale epidemiological studies (Jackson *et al.,* 2003; Riddoch *et al.,* 2004).

Accelerometers have been useful in measuring physical activity in pre-school children as they are objective, lightweight and most particularly because their "black box" design attracts little attention from children (Finn and Speacker, 2000). It therefore makes it less likely that the subject will manipulate or reprogram the accelerometer (Janz, 1994). The MTI/CSA can be programmed to turn itself on and off at designated times and dates as well as on and off during a 24-hr start/stop interval making it possible to distinguish between school and leisure activity or weekday and weekend activity (Janz, 1994). Furthermore, the MTI/CSA has become available with an extended memory, which allows activity to be monitored either for similar periods but with many much shorter epochs or for much longer periods.

This new function allows us therefore to examine short periods of vigorous activity, which might have been previously obscured by alternating periods of rest when the total value for the minute is computed (Welk *et al.,* 2000). Finally, published cross-validated paediatric cut-offs are available for the MTI/CSA accelerometer, which allows examination of patterns of physical activity and sedentary behaviour in young children with greater accuracy (Puyau *et al.,* 2002; Reilly *et al.,* 2003).

Figure 1.2. MTI/CSA Accelerometer

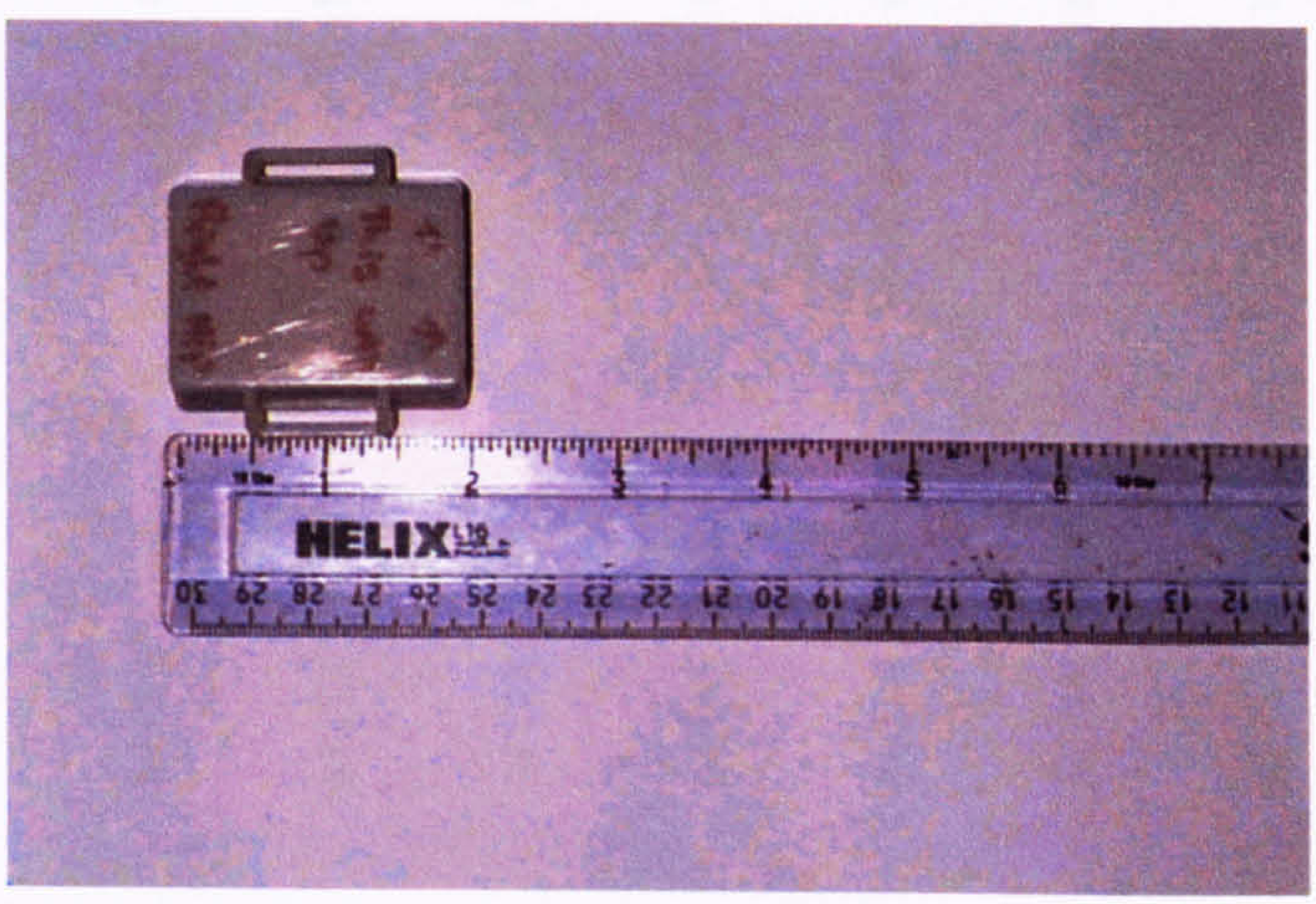


Table 1.3. Validation Studies Of MTI/CSA Accelerometer To Assess Young Peoples Physical Activity

Monitor	Variables	No. Subjects	Age (yr)	Measured Against	Validity	Reference
MTI/CSA®	Mean counts · min^{-1}	31	7-15	HR	r = 0.50 , 0.74	Janz (1994) †
MTI/CSA®	Mean counts · min^{-1}	31	7-15	HR, $\dot{V}O_2$	r = 0.66 , 0.82	Melanson et al (1995) ‡
MTI/CSA®	Counts · $period^{-1}$	11	4	CPAF (DO)	r = 0.87	Fairweather et al (1999) †
MTI/CSA®	Mean counts · min^{-1}	30	10-14	$\dot{V}O_2$	r = 0.77 , 0.87	Trost et al (1998) ‡
MTI/CSA®	Mean counts · min^{-1}	21	8-10	$\dot{V}O_2$	r = 0.81 , 0.88	Louie et al (1999) ‡
MTI/CSA®	Mean counts · min^{-1}	30	8- 11	$\dot{V}O_2$	r = 0.69 , 0.88	Eston et al (1998) ‡
MTI/CSA®	Mean counts · min^{-1}	26	6-16	$\dot{V}O_2$	r = 0.66	Puyau et al (2002) †, ‡
MTI/CSA®	Mean counts · min^{-1}	78	3-4	CPAF (DO)	r = 0.72	Kelly et al (2004) †

CPAF = Children's physical activity form; DO = direct observation; HR = hear rate, r = Pearson product moment correlation coefficient; $\dot{V}O_2$ = oxygen consumption; ‡study conducted under laboratory conditions; †study conducted under free-living conditions

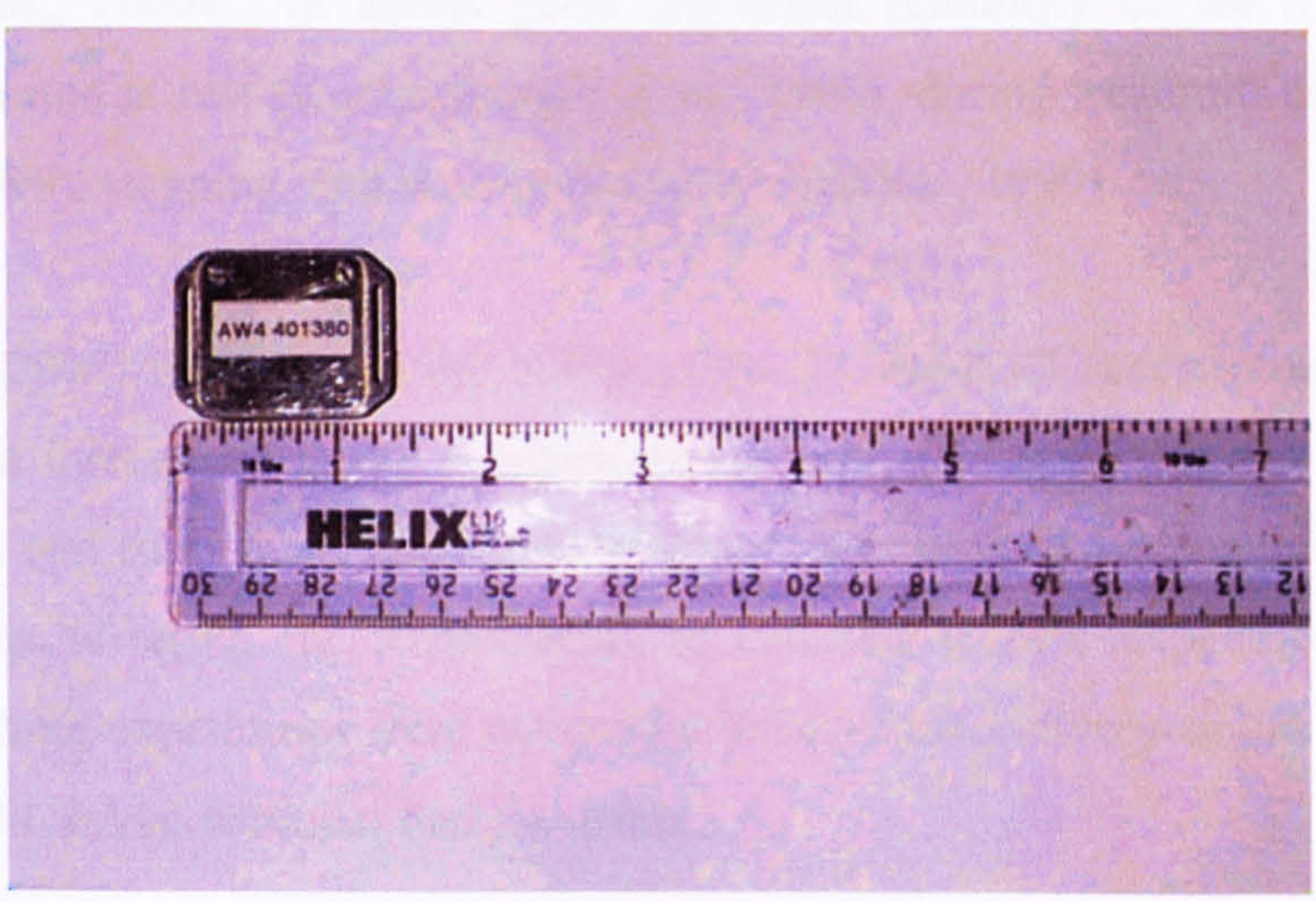
1.12.4. The Actiwatch Accelerometer

One of the most widely used *biaxial / omni directional sensor* accelerometers (i.e. measures activity in two planes) is the Actiwatch® (Cambridge Neurotechnology, UK). The Actiwatch® (Cambridge Neurotechnology, UK) is a small (2.8 x 2.5 x 10.0 cm), lightweight (18g), waterproof (1 m) biaxial accelerometer (Figure 2.2). The Actiwatch can be worn at the wrist, ankle or waist, and contains a sensor capable of detecting acceleration in all directions. Sensitive to <0.05gravity, this type of sensor integrates the degree and speed of motion and produces an electrical current (voltage) that varies in magnitude. An increased degree of speed and motion causes an increased voltage in the sensor. The voltage corresponds to a number of activity counts which the monitor stores. The maximum sampling frequency is 32Hz.

The Actiwatch has been programmed with a calibration coefficient to normalise data between watches. This removes most if not all variation between units due to sensors. However, to date there are no published data available on the reproducibility or between watch differences. A computer clock sets the Actiwatch. The unit marks elapsed time, as it contains a crystal that oscillates 32 times per second. When a sampling epoch is chosen the Actiwatch is then instructed to wait a specific number of oscillations before storing the number of activity counts. This also applies to delayed starting times. The Actiwatch communicates with the computer via a reader/interface unit, which plugs into the RS-232 serial port of the computer; therefore it requires no external power supply. The watch has a short-range telemetric link established between the watch and the reader. Communicating with the watch occurs when it is placed on the reader in the proper position i.e. when the ready LED is lit. Once the watch is placed reading and writing to the watch can occur. A single lithium coin cell watch battery powers the Actiwatch. If the battery runs out while the watch is logging, all the data taken up to that point will be stored. The projected battery life is 180 days, but this will vary depending on the number of times the watch is read or written to. The standard watch can log 8000 data points (each one is an 8bit type). If the epochs are set for one minute the monitor will run consecutively for 5.5 days. However an Actiwatch with 32k memory can run for 32,000 data points and with a one minute epoch can run for 22 days consecutively.

To date there have been very few validation studies involving the Actiwatch. Finn and Specker (2000) evaluated the Actiwatch in 40 children 3 to 4 years of age against 6 hrs of direct observation using the CARS as their criterion method. The within-child correlations between 3-minute Actiwatch counts and CARS scores averaged 0.74. Their results favoured the use of the Actiwatch in assessing physical activity in pre-school children. A more recent study by Puyau et al., (2002) investigated the validity of the Actiwatch using energy expenditure measured by whole body calorimetry as the criterion method in 26 children ages 6-16yr. Mean correlations between energy expenditure and minute-minute Actiwatch counts were significant ($r = 0.78$, $p = 0.06$). The researchers concluded that the Actiwatch was a valid instrument for assessing physical activity in children. Despite the fact the Actiwatch is one of the most popular accelerometers in use there have unfortunately been no reproducibility studies to date. Again these accelerometers are quite expensive costing several hundreds of pounds. Acceptability to the child has as yet not been investigated. The fact that the Actiwatch is tamper proof (due to its black box design) in combination with its waterproof capabilities, make it an attractive option for assessing physical activity in with young children.

Figure 1.3. Actiwatch Accelerometer



1.12.5. Tritrac R3D Accelerometer

Triaxial accelerometers measure accelerations in the vertical (z), horizontal (x), and the mediolateral (y) planes (Welk *et al.*, 1995; Epstein *et al.*, 1996; Nicols *et al.*, 1999; Ott *et al.*, 2000; Welk *et al.*, 2000). The Tritrac-R3D (Professional Products, Division of Reining International, Madison, WI, USA) is the most commonly used triaxial accelerometer. The use of 3-dimensional devices such as the Tritrac accelerometer would appear to offer advantages over 1-dimensional devices but the results of comparisons between them have been equivocal (Welk and Corbin, 1995; Trost, 2001), and it is not clear that trixial or biaxial devices are more accurate than uniaxial devices.

The Tritrac-R3D has a frequency response range of 0.1Hz to 3Hz and measure accelerations of magnitude 0.05 to 6.3 gravity (Ott *et al.*, 2000). The monitor weighs 170.4g and measures 10.8 x 6.8 x 3.3cm (Ott *et al.*, 2000). The power source of the unit is a 9-volt battery. The acceleration signal is integrated and summed over an epoch ranging from 1 to 15mins (Ott *et al.*, 2000). Measuring activity using the 1-minute epoch allows up to 14 days recording of data, this information can be down loaded to the PC. The memory capacity is 20,790 data points. All programming operations are completed using a PC equipped with a Reader Interface Unit (RIU) (Ott *et al.*, 2000). In adults good test–retest reliability of the Tritrac has been demonstrated at rest (Kochersberger *et al.*, 1996), during treadmill exercise (Nichols *et al.*, 1999), stepping, and stationary cycling (Jakicic, 1999).

DeVoe (2001) investigated the utility of the Tritrac-R3D accelerometer as a reliable and valid instrument in the quantification of physical activity while backpacking in the field and to evaluate heart-rate responses and oxygen consumption to assess the feasibility of using the Tritrac-R3D to estimate caloric expenditure. Two 7-day backpacking expeditions were conducted in two consecutive years by a single subject at Grand Canyon National Park, Arizona.

Results showed that the average hiking heart rate ranged front 60% to 77% HR max during the expeditions. The average rate of estimated caloric cost ranged from 6.8 to 11.7 kcals·min^{-1} (equivalent to 408 to 702 kcals·hr^{-1}), indicating a relatively moderate to high level of exertion. The Tritrac had adequate consistency and reliability in the field between the two expeditions in recorded activity counts. However, DeVoe (2001) concluded that the Tritrac underestimated caloric expenditure during backpacking with changes in terrain, and hiking speed contributed to even greater disparity in accuracy.

Freedson et al (1997) evaluated the validity and the inter-instrument reliability of the Tritrac-R3D accelerometer in 81 subjects ranging in age from 6 to 18 years. Each participant completed three treadmill trials consisting of walking/running at 4.4, 6.4, and 9.7 km·h^{-1}, respectively. Consistent with previous laboratory-based validation studies, the Tritrac-R3D was highly correlated with energy expenditure measured by indirect calorimetry ($r = 0.90$). Inter-instrument reliability coefficients for the Tritrac-R3D were quite poor, ranging from 0.32 to 0.59.

Welk and Corbin (1995) evaluated the validity of the Tritrac-R3D Activity Monitor, against heart rate and with a Caltrac Activity Monitor in thirty-five children (ages 9-11 years). The children were monitored on 3 different school days with all 3 instruments.

Results showed the Tritrac to be moderately correlated with the heart rate monitor ($r = 0.58$) and highly correlated with the Caltrac monitor ($r = 0.88$). By taking advantage of the minute-by-minute timing capability of the Tritrac and the heart rate monitors, it was discovered that the correlations between these instruments were highest during free play situations (lunch/recess, recess, after school) and were lower when activity was more limited (class time) or structured (physical education). The ability of the Tritrac to assess activity on a minute-by-minute basis may greatly enhance its overall utility.

Trixial accelerometer devices produce outputs based on acceleration due to body movement, gravitational acceleration, external vibrations, and accelerations caused by excessive movements of the sensor. However, like uniaxial accelerometers triaxial accelerometers are also insensitive to movements that involve changes in resistance (weightlifting), incline (stairs) (Nichols *et al.,* 1999). The use of multiple devices would increase the accuracy of energy expenditure prediction, as a single device worn on a limb is limited to detecting local body movements. The Tritrac R3D is currently the most expensive accelerometer on the market priced at approximately $550 (Freedson and Miller, 2000). To date, there are a number of important concerns about the inter-instrument reliability of the Tritrac R3D accelerometer (Welk *et al.,* 2004). Trost (2001) suggested further investigation of inter-instrument reliability in other settings and populations, poor inter-instrument reliability was a concern. An additional limitation of the Tritrac R3D is its size. The Tritrac R3D measures 11.1 x 6.7 x 3.2 cm, which is considerably larger than the MTI/CSA (5.08 x 4.06 x 1.524cm) and the Actiwatch accelerometer (2.8 x 2.5x 10.0cm). The size of the accelerometer is important in field–based studies especially if the subjects being studied are young children, who are more likely to wear the accelerometer if it is unobtrusive, can be worn underneath clothes when necessary, and does not interfere with their daily activities or preclude participation in common activities such as football or dance.

Furthermore, the Tritrac R3D is no longer manufactured. A newer version of the tritrac R3D accelerometer the 'RT3 Research Tracker' has been released by StayHealthy, Inc (Monrovia, CA). StayHealthy, Inc does not currently provide support for the Tritrac R3D, so it is not possible to recalibrate this accelerometer. The manufacturers web site describing the RT3 monitor pointed out weakness in quality control procedures (lack of pre-production testing of the accelerometers and soldering of individual accelerometers with in the unit) as limitations of the original Tritrac R3D accelerometer. The new RT3 accelerometer is smaller (7.1 x 5.6 x 2.8cm) than the R3D (11.1 x 6.7 x 3.2 cm), and employs a single triaxial accelerometer instead of three accelerometers soldered together (Powell *et al.,* 2003).

However, there is very little research to date on the reliability, validity of the revised RT3. Furthermore there is little information on the inter unit comparability i.e. can data collected using the R3D be compared with data from the RT3. Mahar et al (2004) published the only study to date to examine the equivalent reliability and validity of the Tritrac R3D and the Tritrac RT3 in 60 girls aged 12 to 14 years. Both accelerometers were compared against submaximal $\dot{V}O_2$ during 3 – 5 minute bouts of exercise on a treadmill at self-selected speeds for walking, brisk walking and jogging. Mahar et al (2004) concluded that the RT3 and Tritrac accelerometers have high relative correspondence, but poor absolute correspondence (i.e., the RT3 records higher activity counts than the Tritrac).

1.12.6. Heart Rate (HR) Monitoring

Heart rate (HR) is a physiological parameter commonly used when measuring physical activity (Eston *et al.*, 1998). There is a linear relationship between HR and oxygen consumption during exercise in laboratory conditions (Freedson, 1991). HR monitoring has several advantages as a measure of physical activity in children. HR monitoring is an objective measurement and does not rely on the memory or perception of the subject. Methods that are subjective such as self-reports are difficult for children to compete and are deemed unsuitable for young children (DuRant *et al.*, 1992). HR monitoring is a simple non-invasive method.

The technique is relatively inexpensive, and the equipment is quite advanced so it can store information over a period of time (i.e. days or even weeks). The investigator can receive information on different aspects of physical activity such as time, frequency, intensity and duration (Strath *et al.*, 2001). The validity of HR telemetry has been demonstrated by comparative studies with ECG monitoring, not only in laboratory conditions but also under field conditions (Treiber *et al.*, 1989). Some studies suggest HR is a valid and reliable method for assessing physical activity and inactivity in even young children (DuRant *et al.*, 1992; DuRant *et al.*, 1993; Montoye *et al.*, 1996; Logan *et al.*, 2000).

To adjust for differences in fitness and age among children HR data need to be expressed relative to resting heart rate RHR (Pate *et al.,* 1996a), this correction is done by calculating the physical activity heart rate (PAHR) -25 and PAHR-50, the time spent above 1.25 (light-moderate activity) and 1.50 (more vigorous activities) times resting heart rate respectively. Alternatively, physical activity level can be summarized using the activity heart rate (AHR), the mean of the recorded heart rates minus RHR. However, both the PHAR and AHR are critically dependent on the measurement or calculation of RHR (Logan *et al.,* 2000). Unfortunately, there are various different methods for measuring RHR and there has been no consensus on a "gold standard" measure. This is unfortunate as different values for RHR significantly affects the indices of habitual physical activity PAHR-25, PAHR-50 and AHR (Logan *et al.,* 2000). As a consequence, habitual physical activity can be dramatically over or underestimated by expressing HR relative to different definitions of RHR. It is worth noting that HR method needs individual calibrations, ideally against a maximal fitness test measuring $\dot{V}O_2$. Therefore, this method becomes impractical fr anything but a very small study.

There are limitations to the method of measuring physical activity from HR monitors, which are compounded when children are subjects. Heart rates in the lower ranges of the distribution are affected by factors other than physiological stress such as emotional factors (Riddoch and Boreham, 1995). During sedentary or light intensity activities, an individual's heart rate can be affected by factors other than body movement (Livingstone *et al.,* 1992). Physiological and environmental stress, as well as caffeine and some medications can significantly affect heart rate (Emons *et al.*, 1992). Indeed, a study by Welk et al (1998) found that HR indicators were highly correlated with direct observation under active conditions ($r = 0.79$) but were weakly correlated under inactive conditions ($P<0.05$). Thus HR should only be used as a measure for assessing moderate to vigorous activity and therefore may not be suitable for measuring habitual physical activity in young children.

Additionally, a small child may feel discomfort while wearing the transmitter device, (Montoye *et al.*, 1996). This could not only reduce participant compliance, but also influence the results causing the child to become more active due to "reactivity" (i.e. the child knows they are being monitored so tries to impress the investigator) or become less active due to the discomfort (Montoye *et al.*, 1996). For these practical reasons most researchers who study physical activity in young children now use accelerometry rather than HR monitoring

1.13. Subjective Techniques

1.13.1. Self Report And Interviews

Self-reports methods of estimating physical activity levels are considered subjective because they rely on responses from the child or parent (Kohl *et al.*, 2000). Self-reports are the most commonly employed procedure to measure physical activity and can involve recall or diary methods and can be either interviewer–administered or self-administered. The sporadic nature of children's physical activity (Bailey *et al.*, 1995) makes these activities difficult to recall, quantify and categorise. Also, the less developed cognitive functioning of children compared with adults impacts on their ability to accurately recall intensity, frequency and especially duration of activities (Baranowski *et al.*, 1984; Kohl *et al.*, 2000; Fulton *et al.*, 2001; Sirard and Pate, 2001). Hence, survey techniques should be validated against more stringent measures of physical activity (criterion methods) before extensive use.

Depending on the questionnaire, subjects may be asked to provide information regarding type, time, duration, intensity and frequency of physical activity. Activities are divided into light, moderate and high intensities and each intensity corresponds to a specific MET value. Some questionnaires provide numerical endpoints that group or rank individuals according to their levels of physical activity (Bouchard, 2000). The most common questionnaires estimate leisure time physical activity, physical activity or both (Montoye *et al.*, 1996).

As previously mentioned, self –reports are widely used in large-scale epidemiological studies; however there is widespread concern about their reliability and validity of self-reported data from children (Welk *et al.*, 2000). Estimating physical activity by questionnaire or interview in children generally requires a different procedure or survey instrument than when only adults are involved. Moreover, the potential for error in recall is likely to be greater (Welk *et al.*, 2000).

In fact, most experienced investigators agree that the self-report approach is not appropriate with children younger than about 10 years of age (Montoye *et al.*, 1996; Fox and Riddoch, 2000; Fulton *et al.*, 2001; Kohl *et al.*, 2000). Often with younger children the questionnaire is completed by a parent, teacher or other adult increasing the imprecision of this technique (Baranowski, 1998; Klesges *et al.*, 1990). The self-report procedure differs between children and an adult because of the source of activity to some extent differs. Young children are not employed, so there is no occupational activity. The self-report with children must contain inquiries about participation in physical education classes, recess periods, organised sports (intramural, school, or club), transport to and from school and or recreational activities after school and during weekends. As with adults, information on intensity, frequency and duration of activities should be sought (Montoye *et al.*, 1996). The language used must also be suitable for the age of the child. There appears to be a general consensus that self-report instruments for use with young children should be based on a previous day recall method (Pate, 1993; Sallis *et al.*, 1993). There have been many instruments of this description developed over the years. Examples of reliable and validated instruments include the Perspiration Questionnaire, the Godin-Shepard Questionnaire, the Multi-Item Specific Activity Questionnaire and the Physical Activity Questionnaire for Children (Crocker *et al.*, 1997).

One of the most popular questionnaire based method for assessing physical activity in children is the Previous Day Physical Activity Recall (PDPAR). The PDPAR involves the completion of a questionnaire that requires the recall of the previous day's activities (after school hours) and their relative intensities (Weston *et al.*, 1997). However, this method was clearly developed for an older child (> 9 years) to understand and complete as it contains contextual cues for activities and cartoon illustrations depicting different intensity levels (Weston *et al.*, 1997).

The validity and the reliability of the PDPAR were investigated by Weston *et al* (1997). The reliability was strong as the test –retest reliability co-efficient (r = 0.98) indicated that subject's recall of the previous days physical activity was stable when reported twice within one hour (Weston *et al.*, 1997). Furthermore, the inter-rater reliability (r = 0.99) showed that the scoring protocol for the PDPAR could be used consistently by different investigators (Weston *et al.*, 1997). The validity studies showed that the estimates of energy expenditure and participation in episodes of moderate to vigorous physical activity could be determined relatively accurately from data provided by the PDPAR (Weston *et al.*, 1997). Additionally, it was found that children could accurately recall the type and intensity of activity, but did not accurately recall the specific 30 minutes time block during which they were engaged in an activity (Weston *et al.*, 1997).

A major limitation of the self-report method for assessing physical activity is the inability of children to estimate the duration of an activity very well. In the mind of a child, intensity and joy are often important criteria for the duration of an activity (Montoye *et al.*, 1996). Children, especially young children, have not yet developed the cognitive skills necessary to accurately complete self-reports/questionnaires and struggle to do so (Baranowski *et al.*, 1984). This generally leads to an over estimation of the time that the child spends on activity (Saris, 1986). Indeed one study has shown that children have the potential to over report activity by up to 100% compared to activity minutes assessed by heart rate monitoring (Sallis *et al.*, 1996).

Although little is known about specific cognitive skills required for children to complete self-reports and questionnaires accurately (DuRant and Ainsworth, 1996), it is believed that problems arise as children are not time conscious and do not engage in physical activity in consistent bouts .Previous studies have also shown that children are inclined to over-report the time they some in vigorous activities and under-report time spend in sedentary activities (Montoye *et al.*, 1996). However, Weston et al (1997) when using the PDPAR instrument did not report on sedentary behaviour or vigorous activity.

The PDPAR is flexible in that it can provide a summary of information on the estimate of energy expenditure over a specific period of time or it can record individual bouts of physical activity at a certain level of energy expenditure (Weston *et al.*, 1997). Alternatively, to gain a picture of habitual physical activity which has already been established as being important for health, the PDPAR can be used on several occasions. However one of the main limitations of the PDPAR is that it is geared towards older children i.e. aged 9 years and upwards.

Self-report and questionnaire based methods are the least reliable and valid methods to use with children, as the techniques are subjective. Nevertheless, they do provide a convenient method for assessing activity patterns in large populations, and are the only method that assess mode. Furthermore, some of the previous days recall measures appear to be somewhat more promising. Unfortunately, for developmental reasons they are not appropriate for use with young children, the target age group for this thesis.

1.14. Anthropometric Measures

A variety of methods are available to measure adiposity (Mei *et al.*, 2002), however, many of the methods receive limited use, as they are complex and costly. Height and weight (see Appendix for procedures for measuring height and weight) based measurements are the most pr`actical tools because of their simplicity and low cost (Mei *et al.*, 2002). Of the proxy methods available, there is greatest support for the use of body mass index (BMI).

BMI simply identifies those with excess body fat who are at risk of morbidity. For a child, BMI is not a static measurement, but varies from birth to adulthood, and varies between males and females. Interpretation of BMI values therefore depends on comparisons with population reference data such as the 1990 UK reference data used in this thesis (Cole *et al.*, 1995), and using cut-off points in the BMI distribution (BMI centiles).

However, cut-offs vary from country to country and therefore, different BMI for age values have been used to define overweight and obesity in different populations (Bellizzi and Dietz, 1999). Cole et al (2000) recently proposed more internationally based BMI reference data for children.

Nevertheless, BMI >85th centile and BMI >95th centile relative to a population standard have become widely used to define overweight and obesity respectively (Gortmaker *et al.,* 1996; Whitaker *et al.,* 1997; Troiano and Flegal 1998; SIGN publication no.69, 2003). Despite these limitations there is international support for the use of BMI to define obesity in children, expressed in non-systematic reviews and consensus statements (Cole *et al.,* 1995; Dietz and Bellizzi *et al.,* 1999; Cole *et al.,* 2000). BMI standard deviation (SD) scores were calculated and used to describe the weight status of our subjects i.e. the extent to which our sample was overweight or underweight. By the mid to late 1990's representative samples of children from the UK are consistently reported to be overweight (Reilly *et al.,* 2002) with mean SD score typically 0.3 to 0.6 (Jackson *et al.,* 2003; Reilly *et al.,* 2004).

1.15. Socio-Economic Status

The term socioeconomic status (SES) usually denotes the relative position of individuals, families, or groups into stratified social systems (De Castro Ribas *et al.,* 2003). SES is composed of two associated concepts, social stratification and social inequality. Social inequality refers to the fact that, in virtually all societies, critical social values (e.g. education, occupation, economic resources, prestige, power, information) are not uniformly distributed. Social stratification refers to the process of organisation of social systems (e.g., societies) where individuals, families, and groups are classified into hierarchies (e.g., social classes) according to for example their access to or control of education, wealth, prestige and power. The relative position of individuals, families, and groups in a given hierarchy is frequently converted into a score produced by a scale, and SES is normally indexed by one or a combination of the following prominent indicators: occupation, education and income (De Castro Ribas *et al.,* 2003).

Socio-economic status has long been a prime predictive variable in epidemiological studies. People of lower socio-economic status have lower life expectancy and higher mortality rates from almost all causes of death (Alder *et al.,* 1993) and a variety of morbidities are variably associated with SES (Liberatos *et al.,* 1988; James *et al.,* 1997; Powell *et al.,* 2001; Chalmers and Capewell 2001). The evidence from individual-level studies suggests that childhood socio-economic circumstances contribute to a variety of different causes of death. In particular, childhood conditions appear strongly related to mortality from stomach cancer and hemorrhagic stroke (Galobardes *et al.,* 2004). Childhood circumstances, together with adulthood socio-economic position, contribute to mortality from coronary heart disease, lung cancer, and respiratory-related diseases. (Galobardes *et al.,* 2004).

Two studies, one in the US (Gortmaker *et al.,* 1993) and one in the UK (Sargent and Blanchflower, 1994) have shown that obesity in adolescence and young adulthood is associated with poorer social outcomes in later life (higher rates of poverty and lower rates of marriage, educational attainment, and household income corrected for I.Q.) particularly in women (Dietz 1998). As an explanatory variable in health studies, SES has been used to derive health policy recommendations (Benzeval *et al.,* 1995) and to infer public health implications of dietary needs in different social strata (Smith *et al.,* 1992). In addition, SES has long been an important factor in many studies in the social sciences. In a lengthy review of the use of SES in epidemiology, Liberatos et al (1988) pointed out that most measures are based upon three related measurements: (1) occupation, (2) education and (3) income. Economic indicators such as household income and wealth are used less frequently but are potentially as important as or more important than education (Duncan *et al.,* 2002).

1.15.1. Social Class

A number of different methods for assessment of social class/socio-economic status have been used in the UK. The mostly widely used and accepted method is based on the Registrar General Classification of Occupations (Office of Population Census and Surveys; OPCS 1990). The Registrar-General's class scheme rests on the assumption that society is a graded hierarchy of occupations. The five basic social classes recognised by the Office of Population Censuses and Surveys (OPCS) were described, as an ordinal classification of occupations according to their reputed 'standing within the community'.

These classes are:
Social Class I (professional occupations),
Social Class II managerial and technical occupations),
Social Class IIINM (skilled non-manual),
Social Class IIIM (skilled manual),
Social Class IV (partly skilled),
Social Class V (unskilled).

In practice, individuals are assigned to social classes by a threefold process. Firstly, they are allocated an occupational group, defined according to the kind of work done and the nature of the operation performed. Each occupational category is then assigned as a whole to one or other social class and no account is taken of differences between individuals in the same occupation group, e.g. differences of education or level of remuneration. Finally, persons of particular employment status within occupational groups are removed to social classes different from that allocated the occupation as a whole. Most notably, individuals of foreman status whose basic social class is IV or V are reallocated to social class III, and persons of managerial status are (with certain minor exceptions) placed in social class II (see OPCS, 1980:vi and xi; OPCS, 1991:12).

Despite the wide use of the OPCS (1991) for classification of social class, this method has several limitations worth noting. Firstly, one limitation of socio-economic indicators based on occupational classifications is that they may not comparably capture disparities in working and living conditions across divisions of race/ethnicity and gender. Black and other ethnic minority workers, for example, are more likely than their white counterparts in the same occupations to be exposed to carcinogens and other pathogenic conditions at work, and also to be paid less, even after taking into account job experience and education (Wright *et al.,* 1977). An additional liability of occupation-based measures is that they cannot readily be used for social groups outside of the recognised paid labour force (Krieger *et al.,* 1997). These groups include: non-retired adults who are unemployed, homemakers (primarily women) who do not work outside of the home, persons employed in informal or illegal sectors of the economy and also groups not expected to be in the active labour force, i.e. children and retired adults. Approaches to measuring social or occupational class of these groups usually rely upon finding proxy measures: last or main occupation, in the case of unemployed and retired workers; spouse's occupation, in the case of homemakers; and parents' (or, more typically, father's; OPCS, 1991) class, in the case of children.

However, many modern households are not represented by the stereotypical "nuclear family". As a consequence, many subjects are not readily classifiable. Two British studies indicate that measures of occupational class based on last occupation, for example, are predictive of chronic illness among men and women who are unemployed (Arber, 1987) or retired (Arber & Ginn, 1993).

Despite these limitations, the standard classification of Occupations (1991) has been widely used and is in chapter 7 of this thesis to classify urban Scottish and rural Irish children. As the Irish system for classification of SES is broadly similar, the UK OPCS system was used to classify rural Irish children (Livingstone *et al.,* 2001).

1.15.2. Deprivation Category

The measure of area-level socio-economic characteristics used in chapter 6 of this thesis was the Carstairs deprivation score. This is an established SES measure that has been used in several studies concerned with the association of area-level socio-economic circumstances and health outcomes (Chalmers and Capewell 2001; Armstrong *et al.*, 2003; Galobardes *et al.*, 2004; Jackson *et al.*, 2003; Breeze *et al.*, 2005). Deprivation category is a commonly used as an alternative method to social class for describing a subjects SES in Scotland (Carstairs and Morris, 1991). Socio-economic status can be measured using the Carstairs score (Carstairs and Morris, 1991). The deprivation category score (depcat score) is an area-based measure of deprivation, which has been devised using data from the 1991 census, with the result that relationships against mortality can be determined against the score values, which are calculated at postcode sector.

The measure is composed of four variables:

- Percent persons with no car,
- Percent persons in overcrowded housing,
- Percent persons with household head in semi- or unskilled occupations (social class IV or V),
- Percent men unemployed.

A Z-score is calculated for each postcode sector area in Scotland, these scores are classified into seven (unequal) categories, which range from 1 (most affluent) to 7 (most deprived).

For assessing the impact area-level socio-economic circumstances, a number of different measures are used (e.g. education level and income). Unlike the occupational methods for assessing SES, the depcat score spans relatively large homogeneous geographic areas in terms of their socio-demographic characteristics. Therefore, the major strength of the Carstairs score (unlike SES based on education levels or income) is its combination of information on a number of different aspects of socio-economic circumstances no subject is left 'unclassifiable' a frequently occurring problem when using social class to measure SES (Smith *et al.*, 1998). A further strength of the depcat score is that it has been used in published cohort survival graphs to assess the link between SES and premature mortality. A study by Chalmers and Capewell (2001) showed that deprived people die from the same conditions as affluent people but the deprived people in Scotland die earlier overall. The risk of premature death in middle age is much greater in the most deprived/lower social class backgrounds then the more affluent social classes (Chalmers and Capewell 2001).

One limitation of the depcat score is that it can only be calculated from census data, at 10-yearly intervals, and clearly both populations and area characteristics may change. Another limitation is the depcat score only classifies the area, not the individual. Despite these limitations the depcat score (1991) has been used in chapter 6 of this thesis to examine potential differences in habitual physical activity and sedentary behaviour in young children for deprived versus wealthy families in Glasgow, and chapter 8 of this thesis, to investigating tracking of physical activity and sedentary behaviour in young children.

SES was assessed using two methods, the OPCS method of defining social class at the family level (chapter 6) and the deprivation category at the level of the area (chapters 5 and 7). As previously mentioned, the OPCS method for assessing SES was chosen in order to compare the physical activity and sedentary behaviour of rural Irish and urban Scottish children. In Chapters 5 and 7 the deprivation category method was chosen, as more participants would have been 'unclassifiable' if the OPCS method of defining social class had been implemented. Educational levels and income were not use to assess SES as it was felt that they might not be reported accurately.

1.16. Rationale For Choice Of Methods For Measuring Physical Activity And Sedentary Behaviour Used In This Thesis

In summary, due to the limitations of the doubly labelled water method (i.e. too expensive, does not give information on patterns and frequency of physical activity, intensity and sedentary behaviour) and other forms of indirect calorimery (few studies done on young children), the direct observation technique was used as the criterion method for assessing physical activity and sedentary behaviour in this thesis

Although pedometers and heart rate monitors have been validated in young children it was thought their limitations far outweighed their advantages and therefore accelerometers seemed to be the most appropriate instrument to use in the following studies on physical activity and sedentary behaviour in young children for the following reasons. Firstly, accelerometers provide an objective tool for assessing physical activity and inactivity. Secondly, the many limitations of heart rate monitoring outweigh its advantages and therefore HR monitoring was not chosen to measure physical activity and sedentary behaviour.

The MTI/CSA and Actiwatch accelerometers were chosen instead of the Tritrac R3D trixial accelerometer in the present study because both accelerometers are smaller, lighter and more compact than the Tritrac R3D, and are more acceptable to the young children (Fairweather *et al.*, 1999; Trost *et al.*, 2003). The Tritrac R3D demonstrates poor inter-instrument reliability and may have poor manufacturing standards (Jakicic *et al.*, 1999), and more importantly is no longer available to buy due to the introduction of the RT3 (Welk *et al.*, 2004).

Subsequent to completion of study 3 comparison of two accelerometers for assessment of physical activity in young children the US manufacturers (Mini Mitter, Bend, OR, USA) of the Actiwatch have introduced an 'improved' version of the Actiwatch the 'Actical'. However at the time of completion of this thesis the Actical was not available to purchase in the UK.

In addition both the MTI/CSA and the Actiwatch are cheaper to purchase than the Tritrac R3D accelerometer. MTI/CSA and Actiwatch are by far the most popular accelerometers to use in research (at the time of this thesis). The MTI/CSA accelerometer is currently the only accelerometer that has its own calibrating machine.

Finally, at the start of this thesis financial constraints did not allow the purchase of an expensive Tritrac R3D accelerometer, and the Actical was not available for purchase, and to date cannot be purchased in the UK. As self-reports are not valid for children less than 9 years of age subjective methods were not used to assess physical activity and sedentary behaviour in this thesis (Montoye *et al.*, 1996).

1.17 Rationale For Sampling Period (Epoch) Used In This Thesis

Data were collected in 15 second sampling intervals (epochs) in the studies described in this thesis, however statistical analysis was carried out using 1-minute epochs (15 sec epochs were summed to give 1 minute epochs). At the time of designing the protocols for the studies in this thesis the use of the 1 minute epoch was considered standard practice by researchers in field based studies (Janz, 1994; Eston *et al.*, 1998; Trost *et al.*, 1998; Fairweather *et al.*, 1999; Ott *et al.*, 2000; Trost *et al.*, 2000; Leenders *et al.*, 2001; Finn *et al.*, 2002; Jackson *et al.*, 2002; Metcalf *et al.*, 2002; Puyau *et al.*, 2002; Reilly *et al.*, 2003; Eisenmann *et al.*, 2004; Montgomery *et al.*, 2004; Fisher *et al.*, 2005; Kelly *et al.*, 2005).

The use of a 1-minute epoch has been regarded by some as problematic, and it has been argued on theoretical grounds that shorter epochs might measure vigorous intensity activity more accurately (Trost *et al.*, 2003). Empirical evidence does not bear this out and suggests that the main practical consequence of using 1 minute epochs in children is a small misclassification of some vigorous activity as moderate intensity activity (Nilsson *et al.*, 2002). However, regardless of which epoch is used total counts are the same.

Thus, for the present studies in this thesis the categories of 'moderate and vigorous' intensity physical activity had to be combined, but in practice this probably made little difference since the total time spent in the combined category was so small.

1.18. Rationale For Number Of Days Physical Activity And Sedentary Behaviour Monitored In This Thesis

At present, there is limited evidence documenting recommended measurement periods for physical activity in free-living environments. In the literature, examples of monitoring periods range from as few as 2 days (Finn *et al.*, 2002), frequently 3 (Jackson *et al.*, 2003), or 4 days including 1 weekend day (Janz *et al.*, 2002) to 7 days, up to 2 weeks (Riddoch *et al.*, 2004; Montgomery *et al.*, 2004; Reilly *et al.*, 2004; Fisher *et al.*, 2005; Montgomery *et al.*, 2005). In the early stages of the tracking study 1998/1999 (chapter 8), limited numbers of accelerometers and staff at that time meant that three days (2 week days plus 1 weekend day) was the maximum period of activity monitoring achievable. Study duration of 3 days of activity monitoring was deemed adequate on the basis of a number of criteria. Firstly, practical grounds- our impression was that compliance with physical activity monitoring procedures by families might have deteriorated if a longer period of monitoring was required. Secondly, shorter periods of activity monitoring have been used in young children, yet have produced reasonably stable estimates of activity which relate to biological outcome measures such as bone health (Pate *et al.*, 1996; Janz *et al.*, 2001). Finally, Trost et al (2000) examined age related trends in the reliability of objectively measured physical activity in a population-based sample of US children and adolescents.

Trost et al (2000) estimated that between 2 to 3 days of physical activity monitoring would be necessary to achieve a measurement reliability of 0.80 in young children.

It was therefore decided that satisfactory adherence to the physical activity measurement protocol at age 3 years in chapter 8 would be attained if a minimum of 6 hours per day (approximately 60% of the waking hours for a child of this age; Iglowstein *et al.,* 2003) for a minimum of 3 days (to include 1 weekend day) was recorded (Jackson *et al.,* 2003; Fisher *et al.,* 2004; Montgomery *et al.,* 2004). For the remaining studies of this thesis (chapters 6, 7 and 8) it was decided that 7 consecutive day activity monitoring was desirable as the participants were aged 5 years, and more MTI/CSA accelerometers were available for physical activity/sedentary behaviour data collection.

Prior to physical activity/sedentary behaviour measurements at age 5 years it was decided that satisfactory adherence to the physical activity measurement protocol would be attained if a minimum of 6 hours per day (approximately 60% of the waking hours for a child of this age; Iglowstein *et al.,* 2003) for a minimum of 5 days (to include 1 weekend day) were recorded.

To date there is still no clear consensus on how many days are needed to gain representative measures of habitual physical activity in young children. However, at the time of writing this thesis, 5-7 days consecutive physical activity monitoring was regarded as standard practice (Trost *et al.,* 1999; Trost *et al.,* 2000; Trost *et al.,* 2002; Ekelund *et al.,* 2004; Fisher *et al.,* 2004; Kelly *et al.,* 2004). Recent data have shown that a period of 3 days with a mean monitoring time of between 5 and 10 hours per day is an appropriate sampling period to provide representative values for physical activity and sedentary behaviour with a reliability measure in Scottish children of R= 0.61 (Penpraze *et al.,* 2003). A recent study on age related trends in the reliability of objectively measured physical activity in a population-based sample of US children and adolescents indicted that the 7-day monitoring protocol of physical activity produced acceptable estimates of daily participation in MVPA (R = 0.76 to 0.87: Trost *et al.,* 2000). Recent research shows the most reliable measure of physical activity and sedentary behaviour is a monitoring period of 7 days and 10 hours per day; R=0.80 (Penpraze *et al.,* 2003).

All of the participants in studies in chapters 6 and 7 provided 7 days and a MINIMUM of 6 waking hours physical activity and sedentary behaviour monitoring ensuring a reliability measures of R=0.78 (Penpraze *et al.*, 2003).

These results (Trost *et al.*, 2000; Penpraze *et al.*, 2003) indicate that a 7-day monitoring protocol provides reliable estimates of usual physical activity behavior in children and adolescents and accounts for potentially important differences in weekend versus weekday activity behavior as well as differences in physical activity patterns within a given day (Trost *et al.*, 2000). However, research conducted by Jackson et al (2003) reported no marked day to day or weekday-weekend differences, or nursery school-home differences in the patterns of physical activity in young Glaswegian pre-school children.

1.19. Rationale For Cut-Offs For Accelerometry Output Used In This Thesis

The MTI/CSA accelerometer has become the accelerometer of choice for objectively measuring physical activity in free-living children. However, despite their widespread use, converting MTI/CSA output (cpm) into something meaningful such as intensities of physical activity has led to much debate. Many studies validating accelerometers have been performed in adults (Melanson *et al.*, 1995; Freedson *et al.*, 1998; Bassett *et al.*, 2000; Sirard *et al.*, 2000; Welk *et al.*, 2000; Welk *et al.*, 2004). These accelerometers have been validated against indirect calorimetry in terms of resting metabolism equivalents (MET) (Melanson *et al.*, 1995; Freedson *et al.*, 1998; Bassett *et al.*, 2000; Welk *et al.*, 2000).

MET thresholds used to quantify the time spent in light (< 3METs), moderate (3-6 METs), hard (6-9 METs) and very hard (>9 METs) activities have been defined in adults only (Freedson *et al.*, 1998). The usual practice of defining 1 MET as 3.5ml $O_2 \cdot kg^{-1} \cdot min^{-1}$ is incorrect in children, since their resting metabolic rate (RMR) declines from ~6 mL $O_2 \cdot kg^{-1} \cdot min^{-1}$ at 5 years of age to 3.5 mL $O_2 \cdot kg^{-1} \cdot min^{-1}$ at age 18 years (Schofield, 1985).

Thus, adult derived thresholds are not applicable to children and may introduce errors regarding physical activity levels in children (Puyau *et al.*, 2002; Reilly *et al.*, 2003). Metabolic equations currently in use in studies of physical activity and energy expenditure have been reported to overestimate or underestimate physical activity and energy expenditure under laboratory conditions (Trost *et al.*, 2004).

The cut-offs used in this thesis, applied to MTI/CSA accelerometer output in order to define activities of different intensities, were based on two independent studies (Puyau *et al.*, 2002; Reilly *et al.*, 2003). These two independent studies validated the MTI/CSA accelerometer against energy expenditure (Puyau *et al.*, 2002) and direct observation (Reilly *et al.*, 2003) of physical activity in free-living children undertaking normal activities.

The cut-offs used in this thesis were therefore appropriate for use in free-living children, were age specific and have been used in many published paediatric studies (Puyau *et al.*, 2002; Jackson *et al.*, 2003; Kelly *et al.*, 2004; Reilly *et al.*, 2004; Mongomery *et al.*, 2004; Fisher *et al.*, 2005). The author is aware that this area of research is controversial (Puyau *et al.*, 2002) and that other cut-off points are in use in paediatric studies (Freedson *et al.*, 1997; Trost, 1998; Ekelund *et al.*, 2001; Trost and Freedson, 2002; Puyau *et al.*, 2004; Treuth *et al.*, 2004). However, most of these alternatives do not adequately account for the child-adult differences (previously mentioned) in mass-specific energy expenditure, and are based on treadmill exercise and are inappropriate to use with free-living activity in young children. Furthmore, there are now two published studies which suggest that the appropriate cut-off for MVPA is around 3000 cpm (Treuth *et al.*, 2004; Puyau *et al.*, 2002) and one unpublished study (Mattocks *et al.*, 2005) have also produced similar cut-points.

1.20. Aims

The aims of this thesis are are as follows:

- Simultaneously compare the uniaxial MTI/CSA accelerometer and the biaxial Actiwatch accelerometer against direct observation of total physical activity and minute-by-minute physical activity in 3-4 year olds (chapter 4).

- Cross-validate the proposed 1100cpm cut-off for the assessment of sedentary behaviour in an independent sample of young children (chapter 5).

- Carry out an exploratory study to test the hypothesis that socio-economic status (SES) in young British children may be associated with levels of physical activity and sedentary behaviour. The marked socio-economic difference in obesity risk implies that children from lower SES groups have lower habitual physical activity and higher sedentary behaviour levels (chapter 6).

- Test the hypothesis that rural children are more active than urban children. To test for gender differences in amount (counts per minute over the time monitored) patterns of physical activity and sedentary behaviour (using established cut-offs) (chapter 7).

- Examine the tracking characteristics of physical activity and sedentary behaviour in a relatively large and homogeneous sample of young Scottish children over a two-year period. A secondary aim was to investigate whether physical activity and sedentary behaviour tracked differently between the sexes (chapter 8).

Chapter 2: Generic Methods

2.0. Anthropometric Measures

To characterise the children weight was measured to 0.1kg in light indoor clothing and height to 0.1cm using a portable stadiometer see appendices B and C (SECA Scales, Salter, England Castlemead Leicester Height Measure, Child Growth Foundation, London, England). These measures were used to calculate BMI, which was then, expressed relative to UK 1990 population reference data (Cole *et al.,* 1990) as a standard deviation score (SDS) for each child, using the software provided by the Child Growth Foundation, London.

2.1. Direct Observation Using The Children's Physical Activity Form

The CPAF was originally developed to evaluate a fitness oriented physical US education curriculum (Baranowski *et al.,* 1984). In this observational technique, physical activities are categorised into four *distinct* categories, representing different levels of intensity of movement, by direct observation. The categories are:

1. Stationary, no limb movement (e.g. sitting, lying standing still),
2. Stationary, with limb movement (e.g. bouncing a ball, painting, completing a jigsaw),
3. Slow trunk movement (e.g. walking, twisting),
4. Rapid trunk movement (e.g. running, skipping).

The trained observer records the amount of activity that is occurring in each minute interval and records this by marking a number on a CPAF recording form. Observers are trained to categorise the intensity of the student's movements at 1-min intervals. If the child is carrying out a particular type of movement or is inactive for *greater* then 15 seconds, a mark is placed in the according activity level box. Since the type and intensity of movement can change several times in 1min, observers are instructed to reflect this by checking all categories of the child's activity occurring in that min. Therefore, each 1-min interval may have several different categories, although no one category could be checked twice within the same minute (O'Hara *et al.*, 1989). In this thesis the CPAF was used in Chapter 4 exactly as described by O'Hara et al (1989).

2.1.2. Scoring The CPAF

An intensity of activity point score is calculated for every min of activity by a trained observer. For each minute, the proportion of the minute in seconds was allocated to an activity level depending on whether that level had been checked for that minute. Activity points, which are ordinal in value, were assigned to each of the ordinal levels of movement. That is, each 15 seconds of Stationary no Movement (SNM) received 1 activity point, Stationary Limb movement (SLM) received 2 points; Slow Trunk Movement (STM), 3 points; and Rapid Trunk movement (RTM), 4 points (O'Hara *et al.*, 1989).

For example, if a minute had checks in 3 boxes, it would be scored as follows: 60s/3 checks = 20 s per category checked. If in the above minute the observer had checked the two activity points in the SNM, STM and RTM boxes, the activity point for that one-minute would be calculated as follows:

SNM	=	1	Activity point	=	* 20s	=	20	Activity points
STM	=	2	Activity point	=	* 20s	=	40	Activity point
RTM	=	4	Activity point	=	* 20s	=	80	Activity point
TOTAL	=	140 activity points						

Therefore, the child would have scored as having expended 160 activity points for this minute. Such calculations were conducted for each minute of activity. The minimal numbers of activity points per minute are 60; the maximum activity points are 240 (Appendix D).

2.2. Measurement Of Physical Activity And Sedentary Behaviour

Physical activity and sedentary behaviour were objectively measured using the Computer Science and Applications MTI/CSA WAM-7164 (MTI, Shalimar, Florida) accelerometer. Families were instructed in the use of the accelerometers and requested to place the accelerometer on the right hip, as previously described (Fairweather *et al.*, 1999; Jackson *et al.*, 2003), first thing in the morning (i.e. when they wake up) and remove it before bed, for a period of seven consecutive days. The families were also instructed to remove the MTI/CSA accelerometer before bathing, showering or swimming. . The time when the belt was put on and removed (i.e. when bathing, showering, swimming and bedtime) was recorded. Diaries were completed each day.

Accelerometers produce output in the form of a rate, or 'activity count' per user specified time (e.g. activity count per minute). In order to interpret this in biologically meaningful form, i.e., to convert it to measures of behaviour, cut-off points, which define activities of different intensity, have to be applied to the accelerometer output. Cut-offs of 1100 cpm (Reilly *et al.*, 2003) were used to define sedentary behaviour. Chapter 4 shows that the 1100 cpm cut-off had highest sensitivity and specificity (relative to direct observation) for the correct classification of sedentary behaviour in children of this age (Reilly *et al.*, 2003). Paediatric cut-offs for light intensity activity (up to 3200 cpm) moderate activity (up to 8200 cpm), and vigorous activity (8200 cpm) have been validated against energy expended on activity (Puyau *et al.*, 2002), and these were applied to accelerometer output in the present study in order to provide information on time spent in different intensities of activity.

A 'Raw' summary value (mean total activity cpm) over the measurement period was used as an index of volume or total amount of physical activity undertaken (Fairweather *et al.*, 1999; Jackson *et al.*, 2003). In advance of the each of the biological studies, it was decided that satisfactory adherence to this measurement protocol would have been attained if accelerometers were worn for a minimum of 6 waking hours per day (approximately 60% of the waking hours for children of this age, Iglowstein *et al.*, 2003), for a minimum of 4 days (Jackson *et al.*, 2003).

Jackson et al (2003) found no statistically significant difference in time of day or day-to-day differences in physical activity in young children using this method, and previous studies have suggested that at least 3-4 days of activity monitoring are necessary to obtain stable estimates of habitual activity and sedentary behaviour (Trost *et al.*, 2000; Jackson *et al*; 2003). More recent unpublished data by our group (Penpraze *et al.*, 2003) suggested that reliability was high (77%) so long as 4 days monitoring were carried out for at least 4 waking hours per day.

Chapter 3: Comparison Of Two Accelerometers For Assessment Of Physical Activity In Pre-School Children

3.1. General Introduction

One of the most important limiting factors in the study of childhood physical activity has been the continuing methodological difficulty in measuring physical activity unobtrusively and accurately (Sallis and McKenzie, 1991). Improving the ability to measure accurately children's physical activity in large samples or populations is a necessary first step in assessing determinants of childhood physical activity (Janz, 1994). Measuring physical activity in large-scale epidemiological research projects, in particular, demands a method that is low in cost, acceptable to the subjects, objective and accurate (Janz, 1994).

It is widely believed that children typically engage in frequent, short bursts of activity which are highly transitory (Bailey *et al.*, 1995) and more tortional that physical activities of adolescents or adults (Klesges *et al.*, 1985). Approaches used to measure physical activity in adults have been used frequently with children e.g. heart rate monitoring. However, as adults tend to engage in sustained activity, adult-specific measurement tools may not accurately quantify the activity patterns of children (Ott *et al.*, 2000).

The paucity of data on physical activity in young children (Fairweather *et al.*, 1999; Finn *et al.*, 2002) is in part because accelerometry has only recently become available, and also because of limited evidence of their validity in young children. Fulton et al (2001) highlighted the need to compare the different types of accelerometers currently available for pre-school age children as a research priority for the US Centers for Disease Control and Prevention.

Activity can be assessed by accelerometers in one (uniaxial), two (biaxial) or all three (triaxial) planes of movement. Use of bi or triaxial accelerometers should in theory provide an advantage relative to uniaxial accelerometers in young children; however, this theoretical advantage may not be actually achieved in practice (Welk and Corbin, 1995; Ott *et al.,* 2000).

3.1.2. Accelerometers Used In The Present Study

Two of the most popular accelerometers used in young children at the present time are the bi-axial or 'omni directional' Actiwatch (Cambridge Neurotechnology, England) (Figure 3.2) and the uniaxial MTI/CSA WAM-7164 (Figure 3.3). Both of these instruments have important practical advantages, notably their small size and 'black-box' tamperproof design, which make them particularly suitable for use with young children. There is some evidence on the validity of both the MTI/CSA-7164 and Actiwatch relative to direct observation. Fairweather et al (1999) previously reported on a small study (n=11) of 3-4 year olds in which movement counts from the accelerometer during a period of gymnasium-structured play were highly correlated ($r = 0.79$, $p < 0.01$) with direct observation of physical activity. In a study of forty 3-4 year olds, Finn and Specker (2000) reported a significant median within child correlation coefficient of 0.74 between the Actiwatch and direct observation during a six-hour period in a childcare facility. However, the two instruments have not been compared directly for accuracy in young children.

3.1.3. Basic Electronic Principles Of Accelerometry

The accelerometers (i.e. MTI/CSA and Actiwatch) used in the present study are built from a cantilevered rectangular peizoelectronic biomorph plate and seismic mass. The hardware includes an 8 bit microcontroller with an 8 bit analogue to digital converter (A/D), a specified amount of non-volatile Random Access Memory (RAM), a low power operational amplifier, a charge amplifier, analogue bandpass filters, and a voltage regulator. The circuitry is surrounded in a metal shield and packaged into specific casing. Figure 3.1 illustrates a simplified view of the accelerometers sensor structure.

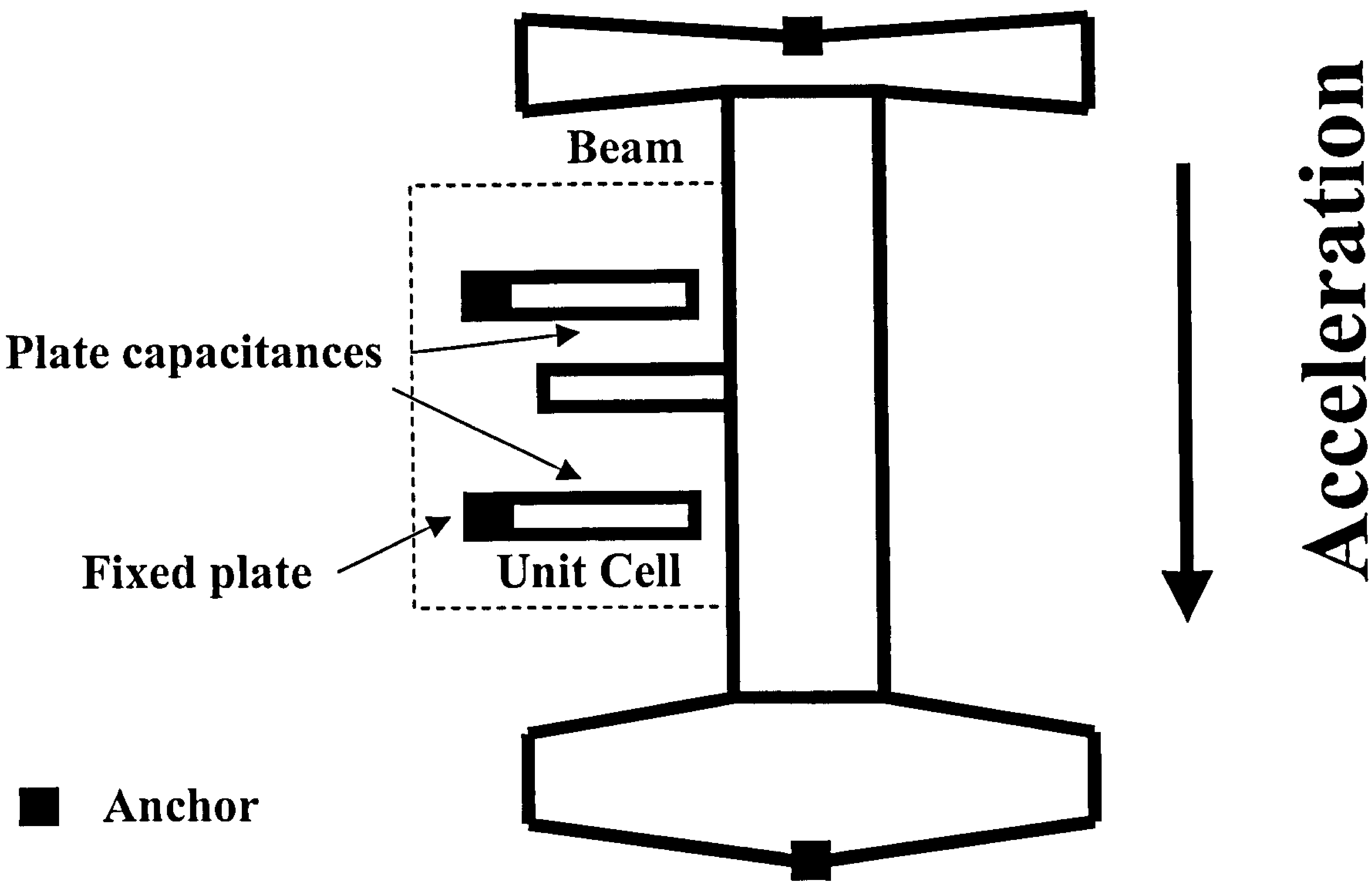


Figure 3.1: Accelerometer Sensor Structure (www.analog.com)

The accelerometer is a differential sensor that comprises fixed and moving plates attached to a beam that moves in response to acceleration. Movement of the beam changes the differential capacitance, which is measured by the accelerometer's electronic circuitry. The accelerometers circuitry drives the differential capacitance sensor and converts the capacitance change into voltage. The output voltage (V_{out}) is a function of both the acceleration input (a) and the power supply voltage (V_s) as follows:

$$Vout = \frac{Vs}{2} - (Sensitivity * \frac{Vs}{5V} * a)$$

For a large-scale factor we increase the sensitivity of the accelerometers measurement but at the expense of decreasing the accelerometers range (i.e. 0.05 to 2G for MTI/CSA; >0.05G for Actiwatch) the voltage out at this stage of the electronic circuit. This signal is then passed through an 8bit A/D converter (i.e. analogue/digital converter).

The A/D converter quantizes the magnitude of the accelerations giving a linear response to acceleration with the pass band i.e. the frequency response to detect human motion and reject motion from other sources. Each A/D value is then summed over a specified interval of time called an epoch. Epochs can be from one second to several minutes. All the data are then stored on the RAM until downloaded by the interface or the accelerometer is re-initialised.

3.2. Aims Of The Present Study

The principal aim of the present study was simultaneously to compare the MTI/CSA and Actiwatch against the criterion direct observation of minute-by-minute physical activity and total physical activity in 3-4 year olds.

3.3. Methods

3.3.1. Subjects And Design

Subjects for this study were 53 apparently healthy 3-4 year old children who attended a weekly adult-led structured play class. This class was chosen as it provided a wide range of activities from sedentary behaviour (e.g. resting) to intense activity (e.g. skipping, running, jumping climbing and swinging from gymnastic equipment) in a short time space (Fairweather *et al.,* 1999). BMI was calculated as previously described in Chapter 3.

Parents of children gave informed written consent to participation and the local research council approved the research. The study was approved by the Ethics Committee of the Royal Hospital for Sick Children.

3.3.2. Direct Observation And Physical Activity

Physical activity was measured with direct observation as the criterion method (CPAF-Children's Physical Activity Form). The CPAF was used as previously described in Chapter 3. A total of three observers were used in this study. The impact of using more than one observer was assessed formally in a preliminary study of 7 children. The preliminary study demonstrated that between observer differences of <4% for the CPAF score could be achieved consistently between the trained observer and the 4 observers (undergraduate students) trained for the purposes of the present study. The same three observers (under the supervision of LK) who took part in the study of inter-observer agreement took part in the subsequent study, which is reported here. The CPAF has previously been reported to show low inter-observer differences in slightly older children (2-4% differences; O'Hara *et al.*, 1989). In one other study between observer differences of <10% for the direct observation method were regarded as acceptable (Finn and Specker, 2000). On the basis of this evidence, data from the four observers were pooled in the present study. Minute-to-minute physical activity and total physical activity using the CPAF were calculated (O'Hara *et al.*, 1989).

3.3.3. Synchronising Accelerometers With Direct Observation

Both accelerometers were initialised and downloaded as per manufacturers instructions. Both accelerometers were synchronised with the direct observation method so that simultaneous comparisons between the methods could be made. This was achieved by setting a stopwatch synchronously with the PC clock on which both accelerometers were set up.

3.3.4. Statistical Analyses

Using the statistical package Minitab 13.2, all anthropometric and activity data were checked for normality using Anderson Darling normality tests prior to statistical analysis. Power to detect significance was calculated using the statistical package nQuery Advisor. For total physical activity

The basis of the comparison was that direct observation represents a criterion method of quantifying total physical activity, against which other methods can be compared. Two approaches to statistical analyses were adopted: for *Total Physical activity* (as the data was skewed) Spearman Rank order correlations were calculed; for *minute-to-minute* correlations Pearson correlations were calculated.

Spearman Rank order correlation between output from each of the accelerometers and CPAF for the summed class data for each child was calculated (n=53). This was intended to provide an assessment of the validity of accelerometry for *relative* assessment of *total* engagement in physical activity, to assess where an individual child lay relative to his/her peers. Total physical activity was defined as accelerometry counts per minute, averaged over the monitored time. To determine the accelerometer's ability to correctly measure total physical activity each child provided 3 summary measures: a summary measure for direct observation; one for physical activity measured using the Actiwatch and one for physical activity measured using the MTI/CSA accelerometer.

For many applications, in epidemiology, the main purpose of accelerometry would be to provide a single summary measure of engagement in activity (total activity), which would be used to make a relative judgement of activity level. This might involve placing a child in a particular quartile of total physical activity level for example. Spearman's rank correlation provides the most appropriate means of testing ability of accelerometry to provide such judgements (Fairweather *et al.*, 1999).

Alternative applications of accelerometry involve more specific judgements about a child's activity intensity, or measurement of changes in intensity in the short term. A within-child, *minute-to-minute* Pearson's (simple) linear correlation with direct observation provides a more appropriate approach to assessing the validity of accelerometry for such applications and so was also used in the present study, as has been previously described (Finn *et al.,* 2000). For example a specific minute of direct observation e.g. minute 24 of CPAF gives an activity score/minute of 120 is compared with minute number 24 of the Actiwatch (e.g. Actiwatch gives a cpm of 120) and minute number 24 of the MTI/CSA accelerometer, which might give a reading of 1950cpm for that minute.

3.4. Results

3.4.1 Characteristics Of Subjects

A total of 59 children/families consented to take part in the present study. Technical failures/lack of co-operation resulted in data being available for 53 (20 boys; 33 girls). Physical characteristics are shown in Table 3.1. Anderson-Darling normality testing showed skewness in the pooled data for height (m) and age (yrs). Boys and girls did not differ significantly for physical characteristics (Table 3.2), activity levels (Table 3.3) within the class, or relationships between accelerometry and direct observation methods. Physical activity data from both sexes were therefore combined (Table 3.4). Mean age of children was 3.5 (SD 0.4) years, with mean BMI 16.4 (SD 1.4), and BMI SDS 0.3 (SD 1.1).

3.4.2 Characteristics Of Exercise Class

Class duration ranged between 39-45minutes. Median total activity count for the MTI/CSA method during the classes was 2192 cpm (range, 931-3992 cpm). Whereas the median total activity score for CPAF and Actiwatch were as follows: CPAF 161 activity points/minute (apm) (range, 123-178 apm), Actiwatch median 840 cpm (range, 218-2981cpm).

Table 3.1. Characteristics of Subjects (Median & Range)

Variable	Group (n=53)	Boys (n=21)	Girls (n=32)
Age (yrs) *	3.6 (2.9,4.3)	3.3 (2.9, 4.2)	3.6 (2.9, 4.2)
Weight (kg) *	16.5 (10.1, 21.0)	16.0 (11.4, 18.8)	16.5 (12.7, 21.0)
Height (m) *	1.0 (0.9, 1.0)	1.0 (0.9, 1.1)	1.0 (0.9, 1.1)
BMI (kg/m^2)	16.3 (11.7, 19.4)	16.6 (13.6, 19.4)	16.2(12.4, 19.4)
BMI SDS	0.4 (-3.1, 2.2)	0.6 (-2.2, 2.2)	0.3 (-3.1, 2.2)

Note: * Indicates skewness (Mann-Whitney U Test)

Table 3.2. Characteristics of Subjects By Gender

Variable		Boys (n=21)	Girls (n=32)
Age +	Median	3.3	3.6
	95% CI for difference	(-0.1, 0.3)	
	P value	0.5	
Weight (kg) +	Median	16.0	16.5
	95% CI for difference	(-1.1, 1.2)	
	P value	0.9	
Height (m) +	Median	1.01	1.04
	95% CI for difference	(0.9, 1.0)	
	P value	0.5	
BMI (Kg/m^2)	Median	16.6	16.2
	95% CI for difference	(-0.8, 0.9)	
	P value	0.9	
BMI SDS	Median	0.6	0.3
	95% CI for difference	(-0.7, 0.6)	
	P value	0.9	

* Indicates significant difference
+ Indicates Skewed data and use of Mann-Whitney Test

Table 3. 3. Physical Activity By Gender (Median & Range)

Variable		Boys (n=21)	Girls (n=32)
CPAF	Median (range)	165.7 (138.0, 178.0)	158.3 (122.7, 177.8)
(apm) +	95% CI for difference	(-0.0 to 30.0)	
	P value	0.2	
Actiwatch	Median (range)	896.0 (320.0, 2981.0)	809.5 (217.8, 2771.7)
(cpm) +	95% CI for difference	(-253.0, 474.9)	
	P value	0.6	
MTI/CSA	Median	2410.4 (1084.1,	2339.3 (2005. 7 ,
(cpm) +		3992.3)	2672.6)
	95% CI for difference	(-244.0, 733.0)	
	P value	0.3	

* Indicates significant difference
+ Indicates Skewed data and use of Mann-Whitney Test

Table 3. 4. Physical Activity For All Subjects (Median & Range)

Variable	**Subjects (n=53)**
CPAF (apm)	160.7 (122.7, 177.8)
Actiwatch (cpm)	840.2 (217.8, 2981.4)
MTI/CSA (cpm)	2154.1 (931.5, 3992.3)

* Indicates significant difference

3.4.3 Validity Of Accelerometry For Measurement Of *Total* Physical Activity

Using Spearman's Rank correlations, total MTI/CSA cpm was significantly positively correlated with total CPAF apm (Table 3.5). MTI/CSA and Actiwatch output were also significantly positively correlated (Table 3.5). However, Actiwatch cpm was not significantly correlated with CPAF apm (Table 3.5).

3.4.4 Validity Of Accelerometry For Measurement Of *Minute-Minute* Within Child Activity

In the 53 children studied, the within-child minute-to-minute correlation between MTI/CSA cpm and CPAF apm was significant and positive ($r = 0.42$, $p < 0.01$; range –0.22 to +0.87). The Actiwatch cpm and CPAF apm were also significantly positively correlated ($r = 0.40$, $p < 0.01$; range –0.41 to +0.82). Power to detect a significant difference from r >0.40 is >99% (based on a 5% significance level).

Table 3.5. Comparison of CPAF against Actiwatch and MTI/CSA for Total Physical Activity

Spearman's Rank Correlations	**R value**	**P-value**
CPAF v Actiwatch	0.15	0.27
CPAF v MTI/CSA	0.59	<0.001

3.5. Discussion

The Actiwatch and other bi-directional accelerometers were developed under the assumption that more planes are better. By measuring motion in more than one plane, these monitors might be better able to quantify physical activity more effectively than uniaxial accelerometers. Indeed, several authors have suggested specifically that omidirectional/triaxial accelerometers may be more sensitive than uniaxial accelerometers to the torsional, non-vertical movement often involved in children's play (Coleman *et al.,* 1997; Eston *et al.,* 1998; Trost *et al.*, 1998). The present study assessed the ability of the two accelerometers to measure total physical activity. This is an important variable and the structured play setting was used as a model for free living activity (Fairweather *et al.,* 1999). As noted previously (Fairweather *et al.,* 1999), these structured play classes represent a useful model of free living activity because intra and inter-child variation in activity is substantial, and a wide range of activities during the class (from sedentary behaviour to intense activity) is undertaken in only a short duration of the class. Because of the short duration of the class, it allows potentially large numbers of subjects to be measured. The present study's assessment of total physical activity was designed as analogous to epidemiological assessment of activity, where the aim is usually to place the child in rank order of total physical activity. The present study showed that for *total* physical activity the MTI/CSA was significantly moderately positively correlated with direct observation ($r = 0.57$; $p<0.01$), while the Actiwatch was not ($r= 0.15$; $p >0.05$). This observation is surprising in the light of results of the minute-minute comparison of Actiwatch and CPAF described below.

Both accelerometers were similarly highly correlated with direct observation for minute–minute assessment of physical activity. This suggests similar performance in the assessment of changes in activity and activity intensity. The present study showed that for *minute–minute* within child physical activity both accelerometers were moderately positively correlated with direct observation (MTI/CSA $r = 0.42$; $p<0.01$; Actiwatch $r= 0.40$; $p <0.01$).

Validation studies of the MTI/CSA have been performed against energy expenditure (EE) using open-circuit indirect calorimeters in children (Trost *et al.,* 1998). Janz (1994) evaluated an earlier MTI/CSA model against heart rate monitoring in children; Finn and Specker (2000) evaluated the MTI/CSA against direct observation in pre-school children. Puyau et al (2002) evaluated both the MTI/CSA and Actiwatch accelerometers against EE in children. Finn and Specker (2000) evaluated the actiwatch in 40 pre-school children aged 3-to-4yrs of age against 6 hrs of direct observation using the Children's Activity Rating Scale (CARS). The within-child correlations between 3-minute Actiwatch counts and CARS scores averaged 0.74. Puyau et al (2002) reported a comparison of Actiwatch and MTI/CSA accelerometers against EE measured by respiration calorimetry in a heterogeneous sample (6-16yrs; n=26). They found relatively little difference between the two accelerometers, with high positive correlations between minute-minute accelerometry data and energy expended on physical activity within a whole body calorimeter (Actiwatch r=0.78; MTI/CSA r=0.66).

A number of study limitations are worth noting. First, this was a pragmatic study in which the accelerometers were tested exactly as they have been used in current practice. In-vitro calibrations of any of the units used with a mechanical 'shaker' (Fairweather *et al.,* 1999) were not carried out since this would not have reflected current practice. A thorough laboratory validation and calibration of these instruments is desirable (Fairweather *et al.,* 1999; Brage *et al.,* 2003), though would have been beyond the scope of the current pragmatic *in-vivo* study.

The use of 1-minute epochs was also a pragmatic decision, reflecting widespread current practice in the field, and the fact that the CPAF was designed for 1-minute epochs. Shorter epochs might provide improved assessment of higher intensity activities in children, though this is not entirely clear at present (Nilsson *et al.,* 2002). Also, while direct observation is regarded as a criterion method for assessment of physical activity, certain limitations are inevitable in any method, which attempts to quantify human movement (O' Hara *et al.,* 1989; Fairweather *et al.,* 1999; Finn and Specker, 2000).

Some inherent weaknesses in the CPAF are noted, notably the fairly arbitrary scheme for construction of a total activity score. However, this scheme has some external validity relative to heart rate monitoring (O' Hara *et al.*, 1989) and similar limitations also affect the alternative direct observation approaches (O' Hara *et al.*, 1989; Fairweather *et al.*, 1999; Finn and Specker, 2000).

Regardless of which accelerometer is used a number of mechanical and electronic issues need to be addressed. The most important issue being, the specification of accelerometers. While the basic principle of accelerometers remains the same, the specifications of each accelerometer are different. The MTI/CSA accelerometer measures accelerations from 0.25 to 2g with a frequency response of 0.25 to 2.5Hz ands a sampling frequency of 10HZ, which detects and records human movement and filters interference. The Actiwatch measures accelerations from >0.05g, unfortunately the upper band is not reported in the manual.

The frequency response for this accelerometer is rather large at 3 to 11Hz with a large sampling frequency of 32Hz. This would suggest that the Actiwatch is *less sensitive* to subtle movements, this observation was also noted by Finn and Specker (2000) who found that the correlation between the Actiwatch counts and their observational method (The Children's Activity Rating Scale, CARS) was greater as the activity of the child increased suggesting that at low levels of activity it was difficult to observe a significant relationship between the Actiwatch and direct observation.

The main strengths of the present study were the relatively large sample size, homogenous sample (narrow age range), use of free-living activities (as opposed to treadmill exercise), and use of a reference method (direct observation) for measurement of physical activity. The present study should provide the best evidence to date as to the comparative validity of CSA and Actiwatch. However, accelerometer accuracy and performance may depend on the intensity of activity (Finn and Specker, 2000), the nature of the activity (e.g. free living or laboratory/treadmill exercise), and the age of the child, so generalisation of the present study conclusion to other populations requires caution. Relationships between accelerometry output and other criterion methods (e.g. energy expended on activity; Puyau *et al.*, 2002) might also be different.

Since this study was conducted many issues have been highlighted which might help explain the Actiwatch's poor *total* physical activity measurement performance. To date there are a few plausible explanations as to why direct observation and Actiwatch were correlated for *minute-minute* within child activity and not correlated for *total* physical activity. Firstly, and most importantly the Actiwatch was originally designed as a sleep watch, the internal processing mechanisms possibly only records peak activity. It is possible that the Actiwatch collects ALL data however at the end of the epoch instead of summing the data recorded the Actiwatch only records the highest activity peak and dumps all other data (Ekelund, 2003; Heil, 2003). In practice, this means that the Actiwatch probably cannot average data over a prolonged period and might explain its poor performance as a measure of total physical activity in the present study.

Secondly, the acceleration frequency and magnitude of the Actiwatch accelerometer on the Actiwatch is possibly too large for human movement and therefore not sensitive to any brief movement, therefore, small movements are not recorded. Thirdly, the Actiwatch was designed to measure and record movements during sleep. Therefore although the accelerometer is omni directional, it is possibly not in the optimum plane for recording physical activity. Finally, these devices are not FULLY waterproof. When they're properly screwed together, the case is watertight. But each battery exchange exposes the electronics to the ambient humidity level. Piezoelectric ceramic sensors are hygroscopic. This means they have an affinity towards moisture absorption. When they absorb moisture they may change their characteristics and sensitivity. So changing the batteries of the used instruments may have potentially varied their sensitivity and hence the accuracy of the accelerometer.

3.6. Conclusions

The present study found a moderate positive correlation between MTI/CSA and direct observation but a weak positive correlation for Actiwatch for *total* physical activity. Many researchers assume that the omni-directional accelerometers may measure total physical activity better due to their ability to record physical activity in more than one plane. However, the present study does not support this suggestion.

Chapter 4: Cross Validation Of The 1100 Count/Minute Accelerometer Output Cut-Off For Measurement Of Sedentary Behaviour

4.1. General Introduction

Sedentary behaviour is an important health construct, which should be considered a separate construct from physical activity (Dietz, 1996). Accurate assessment of sedentary behaviour is important when examining its relationship with a number of health related outcomes e.g. cardiovascular disease, hypertension and obesity. It is also potentially useful for many clinical and public health applications, particularly in the prevention and treatment of childhood obesity (Robinson, 1999; Epstein *et al.*, 2000; Reilly *et al.*, 2002) and the early prevention of cardiovascular disease (Williams *et al.*, 2002). In studies of obesity prevention in children, targeting a reduction in sedentary behaviour may be more effective than the more traditional approach of targeting increases in physical activity (Robinson, 1999; Epstein *et al.*, 2000; Reilly *et al.*, 2002).

However, no simple, objective method has yet been validated for measurement of sedentary behaviour and this has been regarded as a serious barrier to use of sedentary behaviour measurement in clinical practice and public health (Reilly and McDowell, 2003; Livingstone, 2003). Cochrane reviews have recently concluded that randomised controlled trials in paediatric obesity prevention and treatment are greatly weakened by the absence of an objective measure of sedentary behaviour (Campbell *et al.*, 2002; Summerbell *et al.*, 2002). Sedentary behaviour may be both an important mediator of intervention success, and a potentially valuable outcome measure. If the exposure variable, i.e. a proxy for sedentary behaviour does not closely reflect sedentary behaviour, the strength of its relationship to a given outcome is likely to be reduced or eliminated (Casperson, 1989).

Accelerometers have the potential to reduce some of the problems associated with measuring sedentary behaviour. In fact, the migh be even more suitable for the measurement of sedentary behaviour. In physical activity/sedentary behaviour epidemiology researchers are often interested in minutes of time or percentage of time spent in selected physical activity intensity categories that are operationally defined as sedentary, light and moderate-vigorous physical activity. Subsequently, in order to convert the accelerometer output to measures of behaviour, age appropriate cut-off points that define activities of different intensity have to be applied.

4.1.2. Validation Of The 1100 Count/Minute Cut-Off Point

In a previous undergraduate validation study (conducted by J. Coyle and G. Burke), a sample of 30 apparently healthy 3-4 year olds (20 boys; mean age 3.7 years, SD 0.5) were observed using the Children's Physical Activity Form (CPAF) for an average of 100 (SD 17) minutes in nursery. In this study, each minute of direct observation (DO) (direct observation was taken as the criterion method) was compared against its corresponding minute of acclerometry i.e. minute 1 DO was compared with minute 1 accelerometer output. Physical activity was measured simultaneously using the MTI/CSA accelerometer with 1-minute epochs and the two methods were synchronised. *Sensitivity* was defined as the *percentage of inactive minutes correctly classified* by any accelerometry output cut-off (cpm). *Specificity* was defined as the *percentage of non-inactive minutes (all other minutes)* correctly classified. Sensitivity and specificity were calculated for each child for each cut-off point and the resulting values averaged for the sample. Receiver operator characteristic (ROC) analysis identified the 1100cpm cut-off as the optimal accelerometer output cut-off for defining sedentary behaviour in this sample of 30 children in the undergraduate validation study (Reilly *et al.*, 2003a).

4.2. Aims Of The Present Study

The previous undergraduate study was designed to identify the optimum accelerometry output cut-off to denote sedentary behaviour but was based on a sample of only 30 children. There was a need to independently cross validate this cut-off in a separate, larger sample. The aim of the present study was therefore to cross-validate the empirical 1100cpm cut-off for the assessment of sedentary behaviour in an independent sample of young children.

4.3. Methods

4.3.1. Subjects

For the present study sensitivity and specificity were assessed in an independent convenience sample of 52 healthy children (21 boys; mean age 3.5 years, SD 0.5) (table 4.1), who attended a weekly adult led structured play class (previously described in Chapter 4). BMI was calculated for descriptive purposes only. Informed written consent was obtained from parents/carers and the study had the approval of the Yorkhill Hospitals Research Ethics Committee

4.3.3. Direct Observation Of Physical Activity

Physical activity was measured with a criterion method, direct observation, using the Children's Physical Activity Form. The CPAF was used as previously described in Chapters 2 and 3. The subjects (n=52) were observed for an average of 40 (SD 2) minutes using the CPAF, observers (n=3) watched/observed one subject each. In addition, all minutes in which behaviours consisted exclusively of a single category of activity intensity by CPAF (1, 2, 3, or 4) were identified and summary accelerometry output data were calculated for these minutes.

4.3.4. Accelerometer Set-Up To Measure Physical Activity

The MTI/CSA was used to assess physical activity during the class. The accelerometer was initialised and downloaded as per manufacturers instructions. The accelerometers were synchronised with the direct observation by setting a stopwatch synchronously with the PC clock on which the accelerometer was set up.

4.3.5. Statistical Analysis

Data were summarised using standard descriptive statistics. All anthropometric data were checked for normality using histograms of distribution curves and using Anderson-Darling (A.D) normality tests, As there were no significant gender differences he data were pooled for analyses.

One-minute intervals solely in behaviour categories 1 and 2 were defined as ‘inactive minutes’ (true positives), all others as ‘non-inactive minutes’. *Sensitivity* was defined as the percentage of sedentary minutes correctly classified by any accelerometry output cut-off (cpm). *Specificity* was defined as the percentage of noninactive minutes (all other minutes) correctly classified.

Sensitivity and specificity were calculated for each child for each cut-off point and the resulting values averaged for the sample. Receiver operator characteristic (ROC) analysis identified the optimal cut-off for accelerometry output. Data from boys and girls were pooled having established that there were no significant differences between the sexes in the relationships between accelerometry output and direct observation using the CPAF (table 4.1).

4.4. Results

4.4.1 Characteristics Of Subjects

A total of 53 (20 boys; 33 girls) children/families consented to the present study. Anderson-Darling normality testing showed data mean age of children was 3.5 (SD 0.5) years, with mean BMI 16.4 (SD 1.4), and BMI SDS 0.3 (SD 1.1). Boys and girls did not differ significantly for physical characteristics, or activity levels (Table 4.1) within the class.

4.4.2 Cross-Validation Of The 1100 cpm Cut-Off In The Independent Sample

The original undergraduate validation study (n=30) found optimal sensitivity and specificity at an accelerometry output cut-off of 1100 cpm. Mean sensitivity of this cut-off in the present cross-validation (n=53) was 83% (SD 14, 95% CI 78-86%; Figure 4.1). This meant that 438/528 inactive minutes were correctly classified as such using a cut off point of 1100 cpm. Mean specificity was 82% (SD 11, 95% CI 79-86%) i.e. 1251/1526 non-inactive minutes were correctly classified using the cut-off of 1100 cpm (Figure 4.1). Data from boys and girls were combined having established that there were no significant differences between the sexes in sensitivity (83% in boys, 95% CI 75-90; 82% in girls, 95% CI 76-86; p = 0.91 for difference between the sexes) and specificity (82% in boys, 95% CI 76-87; 83% in girls, 95% CI 78-87; p= 0.85 for difference between the sexes).

Predictive values were not calculated as these are dependent on 'prevalence' (in this case activity level) and so are study specific. The impact of activity level on accuracy of classification of activity and sedentary behaviour is discussed briefly below.

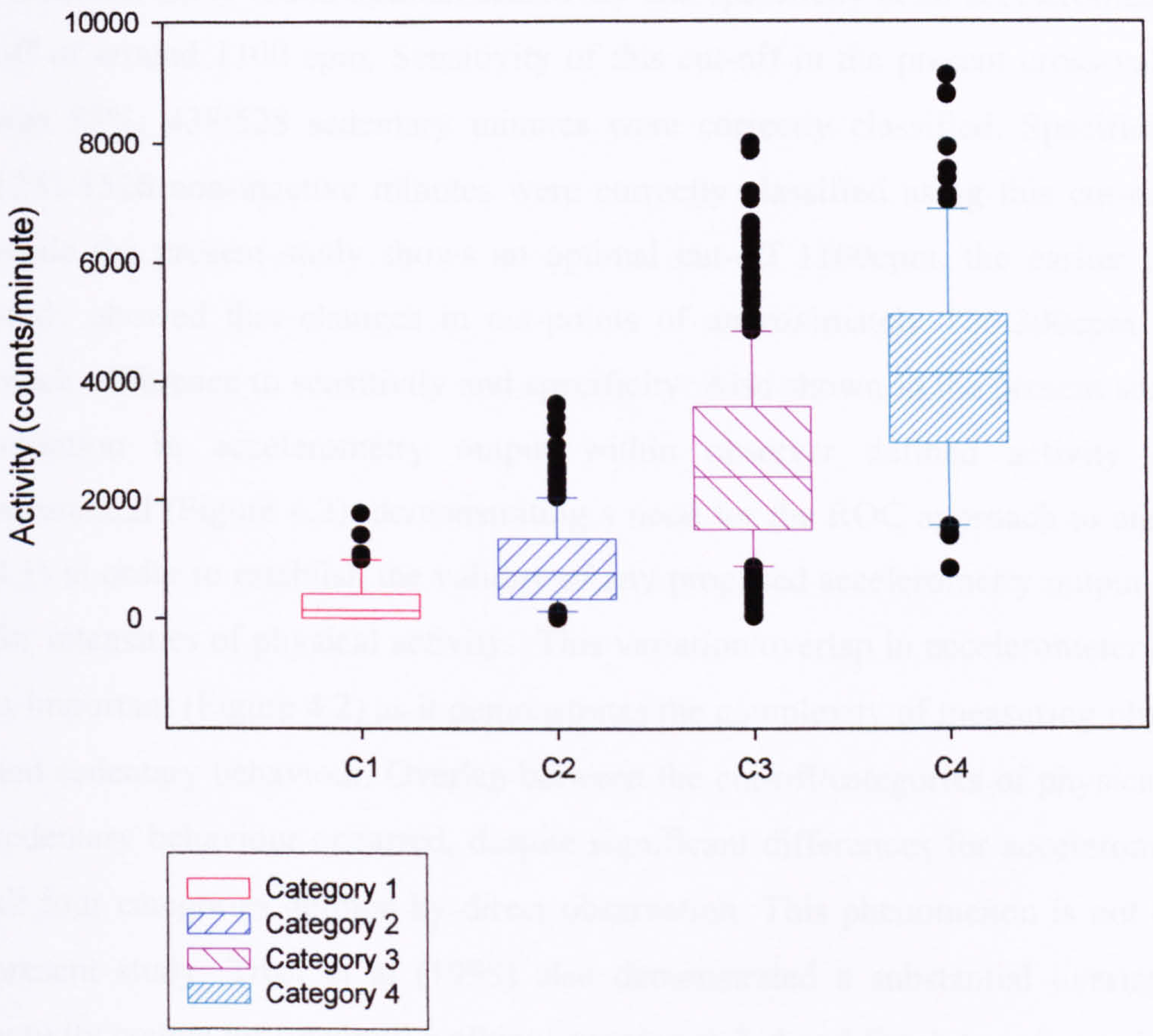
Median accelerometer cpm differed significantly between CPAF behaviour categories 1-4, as might have been expected (Kruskal Wallis test followed by Mann-Whitney tests, $p<0.001$). However, accelerometer output (cpm) overlapped between categories (Figure 4.2).

Table 4.1 Characteristics Of Subjects (Mean ± SD[1])

Variable	**Boys (*n*=20)**	**Girls (*n*=33)**	**95 % Confidence Interval**	**P value[2]**
Age (yrs)	3.5 (0.5)	3.6 (0.5)	(-0.1, 0.3)	0.353
Weight (kg)	15.9 (1.8)	16.2 (1.9)	(-0.9, 1.3)	0.715
Height (m)	1.0 (0.0)	1.0 (0.0)	(-0.04, 0.01)	0.330
BMI (kg/m^2)	16.1 (1.5)	16.4 (1.4)	(-0.8, 0.9)	0.973
BMI SDS	0.4 (1.1)	0.3 (1.1)	(-0.6, 0.6)	0.988
CPAF (apm[3])	161.0 (12.8)	157.5 (13.4)	(-4.0, 12.0)	0.30
MTI/CSA (cpm)[4]	2320 (826)	2114 (639)	(-233, 645)	0.96

Footnote: [1]SDS – standard deviation score relative to UK 1990 reference data, [2]P value – obtained on boys and girls, [3]cpm – activity points per minute, [4]cpm – counts per minute,
* indicates significant difference between boys and girls

Figure 4.1. Title: Box plots of Accelerometry Output Within Each Behavioural Category From The Children's Physical Activity Form (CPAF)



Footnote: Median (quartiles and range) of accelerometry output (counts per minute) for minutes exclusively in CPAF activity categories 1 (n 96 minutes; median 131cpm); 2 (n 205; median 735cpm); 3 (n 374; median 2385cpm); 4 (n 85; median 4171cpm). Differences between categories significant (Mann-Whitney-U tests, p <0.001)

4.5. Discussion

The present study found that a novel application of accelerometry could provide objective assessment of engagement in sedentary behaviour in young children. The present cross-validation study found optimal sensitivity and specificity at an accelerometry output cut-off of around 1100 cpm. Sensitivity of this cut-off in the present cross-validation study was 83%: 438/528 sedentary minutes were correctly classified. Specificity was 82%: 1251/1526 non-inactive minutes were correctly classified using this cut-off. However, while the present study shows an optimal cut-off 1100cpm, the earlier undergraduate study showed that changes in cut-points of approximately 100-300cpm do not make much difference to sensitivity and specificity. Also shown in the present study is that the variation in accelerometry output within observer defined activity categories is substantial (Figure 4.2), demonstrating a need for the ROC approach to analysis (Figure 4.1) in order to establish the validity of any proposed accelerometry output cut off points for intensities of physical activity. This variation/overlap in accelerometer cut-off points is important (Figure 4.2) as it demonstrates the complexity of measuring physical activity and sedentary behaviour. Overlap between the cut-off/categories of physical activity and sedentary behaviour occurred, despite significant differences for accelerometry between all four categories defined by direct observation. This phenomenon is not unique to the present study; Trost et al (1998) also demonstrated a substantial overlap in physical activity counts for treadmill walking/ running at 3, 4 and 6mph (see figure 1 of Trost et al 1998). While there was a significant difference between counts recorded at 3mph and 4mph ($p < 0.05$) and 4mph and 6mph ($p < 0.05$) marked over lap in activity counts were present (Trost *et al.,* 1998).

The lack of appropriate cut-offs for children for defining intensity of sedentary behaviour is unfortunate, because there is enormous interest in determining the level of activity of children. To date (July 2004) only two other published studies have tried to establish valid cut-off counts to define sedentary, light and moderate to vigorous behaviours in free-living young children.

The earliest study in children was conducted by Janz (1994), and evaluated an earlier MTI/CSA (model 5032) using heart rate telemetry as the criterion method (Janz, 1994). Thirty-one children (7-15 yr) wore an MTI/CSA accelerometer and a heart rate telemetry monitor for 12 hours per day for 3 consecutive days. The validity correlation coefficients between accelerometry and heart rate telemetry for each monitored day ranged from r = 0.50 - 0.74. Janz (1994) established exercise intensity based accelerometry count cut-off points using heart rates of 75, 130 and 150 beats·min^{-1} to represent boundaries for sedentary, moderate and vigorous activity in children. These heart rates corresponded to accelerometer count ranges of 25-250, 251-499, and ≥500cpm. These cut-offs proposed by Janz (1994) are however much lower than the 1100cpm (Reilly *et al.,* 2003) cut-off for sedentary behaviour. The possible reason for the large discrepancy between the Janz (1994), the Reilly et al (2003) cut-offs, is that the Janz (1994) procedure involved setting each MTI/CSA frequency range to 0.25 – 5HZ in order to try and reduce inter-instrument variation, the model also detected acceleration ranges from 0.05 to 3.2Gs, (updated models detect acceleration from 0.05 to 2Gs). However, by increasing the detected acceleration ranges of the accelerometer a considerable amount of the accelerometers sensitivity (~30%) is lost, therefore finer body movements were not detected but the MTI/CSA model 5032, which therefore resulted in the establishment of lower cut-off points to determine sedentary behaviour.

The second study that aimed to establish valid cut-off counts to define sedentary, light and moderate to vigorous intensity physical activity in children was conducted by Puyau et al (2002). They reported similar sedentary cut-off counts to define sedentary behaviour (800cpm) to those cross validated in the present study (1100cpm). Puyau et al's (2002) study was designed to validate accelerometer based activity monitors (MTI/CSA and Actiwatch) against energy expenditure (EE) (whole body calorimeter, microwave detector and by heart rate) in children; to compare monitor placement sites; to field test the monitors and to establish sedentary, light, moderate and vigorous cut-off counts. Puyau et al (2002) suggested threshold counts per minute for MTI/CSA were <800, <3200, < 8200 and ≥8200 for sedentary, light, moderate and vigorous categories respectively.

It is worth pointing out that although there is a 300cpm difference between the 800cpm (Puyau *et al.*, 2002) and the 1100cpm cut-off (Reilly *et al.*, 2003), there will probably not be a biologically significant difference, an increase of 300cpm would not move a sedentary child into light the physical activity category defined as counts >801 and <3200 by Puyau et al (2002). For example, using the 800cpm cut-off (Puyau *et al.*, 2002) subjects in the present study spent 72% of their time sedentary. Whereas, applying the 1100cpm (Reilly *et al.*, 2003) cut-off to the data, the subjects in the present study spent 75% of their time in sedentary behaviours.

The present study had a number of strengths. The focus was on a relatively large and homogenous sample of pre-school children. This increases the confidence in the present studies conclusions for this age group, extrapolation of the results to other populations should be considered with caution: the proposed cut-off for sedentary behaviour may be age specific. However, carrying out the necessary cross-validation studies in older subjects should be relatively straightforward.

There are a number of limitations worth noting. Firstly, direct observation of behaviour as a criterion method has a number of limitations, which are noted in Chapter 1. Energy expended on activity is an equally valid criterion but this method was decided against for several reasons. Measuring the energy cost of unrestricted activity in young children is technically difficult, and the results obtained can be difficult to interpret. Extrapolation of laboratory or treadmill exercise to free-living behaviours may introduce errors (Puyau *et al.*, 2002), and describing activity intensity using METs is problematic in children since the appropriate energetic value for a MET is very different from that used in adults and is age-specific (Puyau *et al.*, 2002). If future studies can address these issues then energy expended on activity might more practical as a criterion method for pre-school children.

Finally, limitations in the direct observation method we used probably led to underestimation of the sensitivity of accelerometry for assessment of sedentary behaviour. This bias is likely to have arisen because some minutes (inactive = categories 1 and 2; active = categories 3 and 4) had to be considered as 'non inactive' for the purposes of the ROC analysis. This produced a bias in the assessment of sensitivity, which was felt acceptable, as it was a conservative approach: the performance of accelerometry may be higher than the present estimates indicates.

Potential users of accelerometry should consider the evidence presented in figure 4.1 when deciding on an appropriate a cut-off to use. This will depend in part on whether sensitivity or specificity is the main concern, and whether sedentary behaviour or physical activity is the variable of primary interest. The optimal balance between sensitivity and specificity will depend on the application and future users should consider the potential trade-offs carefully. The accuracy of accelerometry in quantifying behaviour will also depend heavily on the levels of sedentary behaviour and activity in the children being studied.

For the current sample of 3-4 year olds in this particular setting, where approximately 25% of minutes monitored were spent entirely in sedentary behaviour (in level 1-2 of the CPAF) 38% of minutes classified as sedentary by accelerometry were misclassified and 7% of active minutes (all other minutes) were misclassified. In a sample and setting in which 75% of minutes were spent in sedentary behaviour (the converse of what was observed in the present study) predictive values would be approximately switched, with 6% of sedentary minutes misclassified and 39% of active minutes misclassified. In a sample and setting with numbers of sedentary and active minutes equal, approximately 17% of active minutes and 17% of inactive minutes would be misclassified, with a total misclassification of around one-third of total minutes monitored by accelerometry.

4.6. Conclusion

Measurement of sedentary behaviour could have many clinical and public health applications. These include: epidemiological surveys of sedentary behaviour (Dietz, 1996, Livingstone, 2003); sedentary behaviour as an outcome measure in obesity or cardiovascular disease prevention/treatment trials (Campbell *et al.,* 2002; Summerbell *et al.,* 2002; Reilly and McDowell, 2003); assessment of the determinants of sedentary behaviour (Dietz, 1996); assessment of risk factors for obesity (Gortmaker *et al.,* 1996). The ease of use of accelerometry might even permit self-monitoring of sedentary behaviour in clinical practice, a useful element of successful treatment (Epstein *et al.,* 2000).

While the present study concludes that accelerometry could be used much more widely now that validity is established for measurement of both activity and sedentary behaviour the issue of valid age appropriate cut-offs to denote other intensities of activity remains unsolved and is still fraught with controversy (Ekeland *et al.,* 2004; Wilkin and Voss, 2004).

Chapter 5: Differences In Habitual Physical Activity And Sedentary Behaviour In Young Children From Deprived Versus Wealthy Families In Glasgow

5.1. General Introduction

Studies have consistently shown that persons of lower socio-economic status (SES) have increased risk of coronary heart disease, stroke, obesity, some cancers (Adler *et al.*, 1993; James *et al.*, 1997; Powell *et al.*, 2001; Wang, 2001; Muntaner *et al.*, 2004) and early death (Chalmers and Capewell, 2001). Cohort survival graphs show that deprived people die from the same conditions as affluent people but the deprived people die earlier overall (Chalmers and Capewell 2001; Kuh *et al.*, 2002), and the risk of premature death in middle age is much greater in the most deprived social classes than the more affluent social classes (Pappas *et al.*, 1993; Chalmers and Capewell, 2001; Muntaner *et al.*, 2004). The early difference in life expectancy should be of major concern (Langnäse *et al.*, 2002). Evidence also suggests that childhood SES can have a long-lasting impact on the risk of adult obesity (Kinra *et al.*, 2000; Power *et al.*, 2000; Kuh *et al.*, 2002; Power *et al.*, 2003).

The proposed possible reasons for increasing obesity prevalence can be divided into three categories: different genetic makeup, macro nutrient intake and low energy expenditure (Gortmaker *et al.*, 1996; Dietz, 1997; Dietz, 1998; Whitaker and Dietz, 1998). Although studies have shown that genetic factors play a small role in childhood obesity (Parsons *et al.*, 1999).

The fact that the childhood obesity epidemic developed so quickly in the UK means that rapid changes in the genetic "background" are unlikely to be responsible for the epidemic (Parsons *et al.*, 1999), and therefore, changes in lifestyle are probably more important contributors.

Obesity occurs as a result of sustained positive energy balance, i.e. a chronic excess of energy (food) intake and a decrease in total energy expenditure (physical activity). Studies based on data from the UK National Food Survey have shown a 20% decrease in energy intake in adults during 1970-1995 (Prentice and Jebb, 1995). An apparent 20% fall in mean British pre-school children's energy intake also occurred between 1967-1992 (Gregory *et al.*, 1995). The National Diet and National Survey in Young People aged 4-18 years (Gregory *et al.*, 2000) also showed a significant decrease in energy intake in British children, suggesting decreasing energy expenditure through decreased physical activity may be the reason for secular trends in childhood as well as adult obesity (Trioianio *et al.*, 1998; Reilly and Dorosty, 1999). However these results need to be viewed with caution as both studies collected energy intake data using self-report and under-reporting could have occurred. Further progress in understanding the role of nutrition and physical activity/sedentary behaviour in childhood in relation to adult obesity is limited by methodological problems of measuring these factors over extended periods of time. It may well be important to consider indirect measures of early life environment, which provide clues as to the timing of aetiological influences on adult obesity (Power and Parson, 2000). Once such indicator is social class.

In the developed world, children from higher socio-economic status (SES) have been reported to participate in organised sports to a greater degree than children from low SES (Yang *et al.*, 1996; Crespo *et al.*, 1999; Harro *et al.*, 1999). While in developing countries, low SES children have been found to be more physically active than their higher SES counter-parts largely due to increased energy expenditure from daily transportation as low SES children may be more likely to walk or cycle to school (Kemper *et al.*, 1996).

Data investigating the impact of SES on children's physical activity in the UK have revealed conflicting results (Kinra *et al.*, 2000; Woodfield *et al.*, 2002; Mallam *et al.*, 2003). However, further *objective* data are needed to verify the impact of SES on physical activity and sedentary behaviour in young children. Presently, there are insufficient data on the impact of SES on *objectively* measured habitual physical activity and sedentary behaviour in young children.

5.1.2. Social Class And Obesity

The National Health Survey of 5,362 adults in the UK revealed that both men and women who had been raised in manual-class homes were significantly more likely to be overweight at age 36 years than those from non-manual homes (Braddon *et al.*, 1986). Similarly, the National Child Development study of over 9,000 people showed that social class differences in obesity were established at an even earlier age; by age 23 years the difference between higher and lower social classes in the percentages of obese persons was threefold among men and twofold among women (Power and Moynihan, 1988).

Data concerning social class and BMI among adults are collected regularly as part of the Health Survey for England. In both the first survey in 1991 (White *et al.*, 1993) and the most recent survey in 1996 (Prescott-Clarke and Primatesta, 1998), a lower mean BMI was demonstrated in women from non-manual rather than manual households, but the opposite was found in men. Both surveys demonstrated a clear social gradient in the prevalence of obesity in women, but no clear pattern in men (Parsons *et al.*, 1999). Several observations have been made about the relationship between physical activity and social class. Firstly, modern machinery has dramatically decreased physical activity involved in all types of work (Hill, 2004). As a result, heavy occupational physical activity is no longer exclusively associated with lower social class occupations. Secondly, higher social class may provide more opportunity for recreational exercise, together with social pressure towards such exercise. Wilson (1980) reported a dramatic increase in recreational physical activity in higher social class groups.

Thirdly, higher SES women may be more knowledgeable about the benefits of exercise (Powell *et al.,* 2001). The paediatric obesity epidemic in the UK has had a disproportionate impact on children from poorer families: obesity risk is higher in these children (Kinra *et al.,* 2000; Reilly *et al.*, 2000; Woodfield *et al.,* 2002; Armstrong *et al.,* 2003). In the US, children who lived with single mothers, unemployed parents or non-professional parents were shown to be significantly more likely to become obese (Strauss and Knight, 1999).

Kinra et al (2000) studied the association between SES and childhood obesity in 20 973 British children between the ages of 5 and 14 years. Kinra et al (2000) found a strong inverse association between social deprivation (measured using the Townsend index, a geographically based measure of deprivation) and childhood obesity, although obesity in children was defined using a slightly different criterion (BMI $>98^{th}$ Centile) and no attempt was made to analyse confounding factors.

Armstrong et al (2003) investigated the possibility of existence of social inequalities in under-nutrition and obesity in British pre-school children. This retrospective, cross-sectional study routinely collected data from a very large sample of 74,500 Scottish pre-school children aged 39-42 months in 1998. Obesity was defined as BMI $\geq 95^{th}$ centile (relative to the UK 1990 reference data, Cole *et al.,* 1995) and severe obesity $\geq 98^{th}$ centile (relative to the UK 1990 reference data, Cole *et al.,* 1995). Socio-economic status was classified using the same method as used in the present study the Carstairs deprivation category (Carstairs and Morris, 1991). Results from Armstrong et al (2003) demonstrated a significant relationship between low SES and obesity (χ^2 goodness of fit, p <0.001). Armstrong et al (2003) concluded that their study showed that the risk from obesity is much higher than expected and associated with social deprivation at an early age.

The National Diet and Nutrition Survey: young people aged 4-18 years survey reported *no* significant differences in mean daily intake of energy for boys or girls aged 4-18 years associated with social class (Gregory *et al.,* 2000). Marked socio-economic differences in mean daily dietary energy intake are not evident from dietary surveys in British children aged 4-18 years (Gregory *et al.*, 2000). Mean energy intakes for boys from non-manual home backgrounds were 8.1MJ/day and for those from a manual home background 8.0MJ/day. Females from non-manual houses had a mean energy intake of 6.8MJ/day, whereas females from manual houses had a mean energy intake of 6.6MJ/day (Gregory *et al.*, 2000). However, among boys whose parents were in receipt of state benefits there was a marked difference in mean daily energy intake. Boys living in a household receiving benefits had a mean energy intake of 7.2 MJ/day, significantly below that for boys living in non-benefit households, 8.3 MJ/day.

Among boys mean energy intake were lowest for those living in a household where the gross income was below £160 per week, and the highest for those in households with a gross weekly income of £400 to £600 ($p<0.01$). For girls the pattern was similar although the differences were not statistically significant (Gregory *et al.*, 2000).

However, as the method for data collection on energy intake was surveys, the results must be viewed with caution. As previously mentioned in chapter 2, survey, diary and other subjective measures are fraught with inaccuracies due to under or over reporting. Therefore, the association between childhood obesity and deprivation is unlikely to occur due to marked differences in total energy intake alone. The epidemic of childhood obesity that occurred in the UK in the 1990s resulted largely from increasing sedentary behaviour, decreasing physical activity coupled with consumption of energy dense diets, suggesting a reduction in physical activity is partly responsible (Troiano *et al.*, 1998). Presently, there are insufficient data on SES and objectively measured physical activity and sedentary behaviour in young British Children (Woodfield *et al.,* 2003).

5.2. Aims Of The Present Study

The aim of the present study was to carry out an exploratory study to test the hypothesis that socio-economic status (SES) in young British children may be associated with lower levels of physical activity and high levels of sedentary behaviour in children from lower SES groups.

5.3. Methods

5.3.1. Subjects

Two groups of children of distinct socio-economic status (SES), an affluent and deprived group were recruited. Children were recruited from primary 1 of two distinct types of school, state and private sector. This produced 116 children who were available for the study. Of the original 116 children initially recruited, only 78 were eligible for inclusion in the study. The remaining 38 were not eligible for inclusion in the study as the children failed to meet the entry criteria, i.e. they did not live in deprivation categories 1, 2 or 6, 7. Measurements of habitual physical activity and sedentary behaviour were therefore carried out in 78 (39 pairs) of children. BMI was calculated as previously described in Chapter 3, and these measurements were used for descriptive purposes only.

The SES of each family was characterised using the Carstairs Score, a geographically defined index based on postal sector of the family residence as described in more detail in chapters 2 and 3 (Carstairs *et al.,* 1991). The fact that both groups attended different types of school increases the confidence that there were real SES differences between the two groups. Children from the affluent group were pair matched for gender, age, BMI and school days/school holidays with children from the deprived group, i.e. one boy from the affluent group was matched with one boy from the deprived group. Both boys were the same decimal age, had similar BMI, and were monitored during the same week.

All families gave informed written consent and the study had the approval of the Yorkhill Hospitals Ethics Committee.

5.3.2. Sample Size

A pilot study was conducted which compared physical activity data measured using MTI/CSA accelerometers in 10 pairs of children. A power calculation based on paired data suggests that with 39 pairs of children a difference of 100cpm between the affluent and the deprived groups with approximately 0.9 or 90% power would be detected at p = 0.05 (Machin and Campbell, 1998). This was based on a difference of 100cpm and a standard deviation of differences of approximately 200cpm with a standardised significant difference level of 0.50, with a 1 tailed test resulting in 39 pairs of children with a power of 90%. Paired studies with as few as 20 well-matched pairs have been adequate to detect the origin of subtle differences in obesity risk have been other groups (Reilly *et al.,* 1998).

5.3.3. Measurement Of Physical Activity And Sedentary Behaviour

Physical activity and sedentary behaviour were objectively measured using the MTI/CSA WAM-7164 (MTI, Shalimar, Florida) accelerometer. In advance of the study, it was decided that satisfactory adherence to this measurement protocol would have been attained if accelerometers were worn for a minimum of 6 waking hours per day (approximately 60% of the waking hours for children of this age, Iglowstein *et al.,* 2003), for a minimum of 4 days (Jackson *et al.,* 2003).

5.3.4. Statistical Analysis

Using the statistical package Minitab 13.3, all data were checked for normality prior to statistical analysis using descriptive statistics, histograms with normal distribution curves and using Anderson-Darling (A.D) tests of normality. Group anthropometric characteristics and physical activity/sedentary behaviour patterns of the 39 affluent and the 39 deprived subjects were described using basic descriptive statistics. As the group data were skewed, Mann-Whitney U test (unpaired) were used to test the significance of any differences in anthropometric characteristics, engagement in physical activity or sedentary behaviour between the 39 affluent and the 39 deprived subjects. For the paired analyses Wilcoxon signed ranked test (paired) were used to compare one affluent child (e.g. girl) to one deprived child (e.g. girls). As physical activity/sedentary behaviour data were skewed Wilcoxon signed ranked test were carried out on the percentage of time spent in each physical activity intensity (i.e. sedentary/inactive, light moderate to vigorous MVPA) between the affluent and the deprived children.. Antropometric data and physical acivity/sedentary behaviour data were analysed separately by gender using paired –tests and Wilcoxon signed ranked test respectively.

5.4. Results

5.4.1. Characteristics Of Subjects

From the 116 families initially recruited, 78 families, 39 pairs (19 pairs of boys, and 20 pairs of girls) were included in the final analysis as they met the inclusion criteria for age, gender, deprivation category and could be paired. The characteristics of the 78 children are shown in table 5.1. The 39 pairs of children did not differ significantly for age (paired t-test, $p = 0.17$), body mass index (paired t-test, $p = 0.32$), or body mass index standard deviation score (paired t-test, $p = 0.34$), relative to UK 1990 reference data (an index of under and overweight). Characteristics of affluent and deprived boys and girls are shown in tables 5.2, 5.3.

5.4.2 Duration Of Monitoring

Median duration of activity monitoring of the 78 children over the 7-day period was 77 hours (range 37.8, 90.1 hours) (table 5.1). All 78 children provided a minimum of 4 days activity-monitoring data with a minimum of 6 hours per day. Median duration of activity monitoring in the affluent children was 77 hours (range = 41 - 90), and 77 hours (range = 38 - 90) for the deprived children (Table 5.1). There were no significant differences in the mean duration of activity monitoring between the affluent group and the deprived group (Wilcoxon signed ranked test p= 0.19; 95% CI = -131.0 - 22.0). Analysis by gender showed no significant difference in the median duration of activity monitoring between the affluent and deprived groups (Tables 5.2, 5.3).

5.4.3. Differences In *Total Physical Activity* Between Socio-Economic Groups

Total physical activity was expressed as accelerometry counts per minute, averaged over the entire recording period. Total physical activity did not differ significantly between pairs for affluent and deprived participants. Median accelerometry counts per minute in the affluent participants was 728 cpm (range 419-1061 cpm) and 763cpm (419-1072 cpm) for the deprived participants (Wilcoxon signed ranked test p= 0.59; 95% CI = -3, 5; Table 5.1). There were also no statistically significant differences in total physical activity between affluent and deprived participants when considered separately by gender (Wilcoxon signed ranked test, $p > 0.05$; Tables 5.2, 5.3).

5.4.4. Differences In Time Spent In *Sedentary Behaviour* Between Socio-Economic Groups

Median waking time spent in sedentary behaviour was not significantly different for the two groups (affluent participants, 79% (range 68-90) vs. 78% (range 67-89) for the deprived participants (Wilcoxon signed ranked test, p = 0.13; Table 5.1; Figure 5.1). When the data were analysed separately by gender, there was a statistically significant difference in the median percentage of time spent by boys in sedentary behaviour, (Wilcoxon signed rank test, p=0.01 (Tables 5.2, 5.3).

5.4.5. Differences In Time Spent In *Light Intensity Physical Activity* Between Socio-Economic Groups

Median time spent in light intensity physical activity by the affluent group was 17% (range 9, 24), whereas the deprived group spent 18% (range 10, 34) of their time in light intensity activity. Median waking time spent in light intensity activity did not differ significantly between the two groups (Wilcoxon signed ranked test, p = 0.44; Table 5.1; Figure 5.2). In the boys, time spent in light intensity activity was significantly higher in the deprived group (19% vs. 23%; Wilcoxon signed ranked test, p=0.01; Tables 5.2, 5.3).

5.4.6. Differences In Time Spent In *Moderate-Vigorous Physical Activity* Between Socio-Economic Groups

Median waking time spent in MVPA by the affluent group was 3% (range 0, 7), and was essentially the same as the deprived group spent, who spent 3% (range 1, 9) of their time in MVPA. Time spent in MVPA intensity activity was very small in both sexes in both groups, and was not significantly different between the affluent and deprived groups (Wilcoxon signed ranked test, p = 0.98; Table 5.1; Figure 5.3). There were no significant differences when MVPA data were analysed separately by gender (Tables 5.2, 5.3).

Table 5.1. Characteristics Of Subjects (N = 78; Median & Range)

Variable	All children (n =78)	Affluent Group (n= 39)	Deprived Group (n= 39)	95% CI[6]	p value[7]
Age (years)	5.6 (4.5, 6.4)	5.7 (5.1, 6.4)	5.5 (4.5, 6.4)	(-0.1, 0.4)	0.17
Weight (kg)	20.9 (12.3, 34.1)	21.1 (15.3, 34.1)	20.1 (12.3, 32.9)	(-0.6, 2.9)	0.15
Height (m)	1.12 (1.02, 1.27)	1.14 (1.05, 1.27)	1.11 (1.02, 1.25)	(-0.01, 0.04)	0.16
BMI (kg/m^2)	16.4 (10.5, 24.3)	16.6 (13.9, 24.3)	16.1 (10.5, 23.7)	(-0.5, 1.4)	0.32
BMI SDS[1]	0.6 (-5.7, 3.9)	0.7 (-1.5, 3.9)	0.4 (-5.6, 5.3)	(-0.3, 0.8)	0.34
Total Hours Monitored	77.1 (37.8, 90.1)	77.2 (41.2, 90.1)	77.1 (37.8, 90.1)	(-131.0, 22.0)	0.19
Total Physical Activity (cpm)[2]	763.5 (419.0, 1372.0)	728.0 (419.3, 1061.2)	763 (419.0, 1372.1)	(-2.5, 4.5)	0.59
% Time in Light Intensity Activity[3]	17.8 (9.1, 33.7)	17.2 (9.1, 29.4)	18.3 (10.0, 33.7)	(-143.0, 44.0)	0.44
% Time in MVPA[4]	3.2 (0.5, 9.1)	3.2 (0.5, 7.2)	3.0 (0.9, 9.1)	(-31.5, 31.0)	0.98
% Time in Sedentary Behaviour[5]	78.6 (59.1, 90.3)	78.7 (68.2, 90.3)	77.6 (66.8, 89.0)	(-26.0, 316.0)	0.13

[1]SDS – standard deviation score relative to UK 1990 reference data, [2]cpm – counts per minute, [3]percent of time spent in light intensity activity, [4]%MVPA – percent time spent in moderate and vigorous physical activity, [5]percentage of time spent in sedentary behaviour, [6]95% CI – 95% Confidence Interval, [7]P value – obtained on performing Wilcoxon signed ranked tests for difference between affluent and deprived children, * indicates significant difference between affluent and deprived children

Table 5.2. Characteristics Of Subjects For Affluent And Deprived Subjects By Gender

Variable		Affluent Boys (n=19)	Deprived Boys (n=19)	Affluent Girls (n=20)	Deprived Girls (n=20)
Age (yrs)	Median (range)	5.7 (5.2, 6.4)	5.5 (4.6, 6.4)	5.6 (5.1, 6.2)	5.5 (4.5, 6.4)
	95% CI for difference	(-0.2, 0.7)		(-0.2, 0.6)	
	p value[6]	0.17		0.23	
Weight (kg)	Median (range)	21.1 (15.3, 34.1)	21.1(15.3, 28.1)	20.4 (16.8, 28.6)	19.8 (12.3, 32.9)
	95% CI for difference	(-1.6, 4.5)		(-1.3, 2.9)	
	p value[6]	0.31		0.32	
Height (m)	Median (range)	1.14 (1.05,1.27)	1.11 (1.03, 1.25)	1.14 (1.07, 1.23)	1.11 (1.03, 1.23)
	95% CI for difference	(-0.02, 0.06)		(-0.01, 0.05)	
	p value[6]	0.32		0.28	
BMI (kg/m^2)	Median (range)	16.9 (13.9, 24.3)	16.1 (10.9, 21.1)	16.4 (14.0, 19.9)	16.2 (10.5, 23.7)
	95% CI for difference	(-0.9, 2.5)		(-1.1, 1.2)	
	p value[6]	0.27		0.90	
BMI SDS[1]	Median (range)	1.0 (-1.5 to 3.9)	0.7 (-1.2 to 3.0)	0.6 (-1.1 to 2.1)	0.4 (-5.6 to 3.3)
	95% CI for difference	(-0.8 to 1.4)		(-0.4 to 0.8)	
	p value[6]	0.53		0.62	

[1]SDS – standard deviation score relative to UK 1990 reference data, [2]cpm – counts per minute, [3]percent of time spent in light intensity activity, [4]%MVPA – percent time spent in moderate and vigorous physical activity, [5]percentage of time spent in sedentary behaviour, [6]P value – obtained on performing Wilcoxon signed ranked tests for difference between affluent and deprived children, * indicates significant difference between affluent and deprived children.

Table 5.3. Physical Activity Intensities For Affluent And Deprived Subjects By Gender.

Variable		Affluent Boys (n=19)	Deprived Boys (n=19)	Affluent Girls (n=20)	Deprived Girls (n=20)
Total Hours Monitored	Median (range)	77 (41, 90)	75 (38, 87)	77.5 (42, 87)	76.2 (47, 87)
(hrs)	95% CI for difference	(-3.7, 7.4)		(-4.8, 5.0)	
	p value[6]	0.61		0.99	
Total Activity (cpm)[2]	Median (range)	768 (477, 1012)	852 (618, 1363)	718 (419, 1061)	663 (434, 1372)
	95% CI for difference	(-232.0, -22.0) *		(-57.0, 117.0)	
	p value[6]	0.01		0.41	
% Time in Light	Median (range)	18.6 (10.8, 29.4)	(-7.1, -1.4) *	16.9 (9.1, 21.1)	15.7 (10.0, 24.0)
Intensity Activity[3]	95% CI for difference	22.5 (15.5, 33.7)		(-1.4, 2.0)	
	p value[6]	0.01		0.66	
% Time in MVPA[4]	Median (range)	3.2 (1.0, 5.9)	4.0 (1.7, 7.3)	3.2 (0.5, 7.2)	2.5 (0.9, 9.1)
	95% CI for difference	(-1.9, 0.5)		(-0.7, 1.1)	
	p value[6]	0.3		0.51	
% Time in Sedentary	Median (range)	77.0 (68.2, 86.0)	73.5 (59.1 to 82.0)	80.1 (72.5, 90.3)	80.5 (73.3, 89.0)
Behaviour[5]	95% CI for difference	(0.8, 8.6) *		(-2.2, 1.4)	
	p value[6]	0.01		0.74	

[1]SDS – standard deviation score relative to UK 1990 reference data, [2]cpm – counts per minute, [3]percent of time spent in light intensity activity, [4]%MVPA – percent time spent in moderate and vigorous physical activity, [5]percentage of time spent in sedentary behaviour, [6]P value – obtained on performing Wilcoxon signed ranked tests for difference between affluent and deprived children, * indicates significant difference between affluent and deprived children.

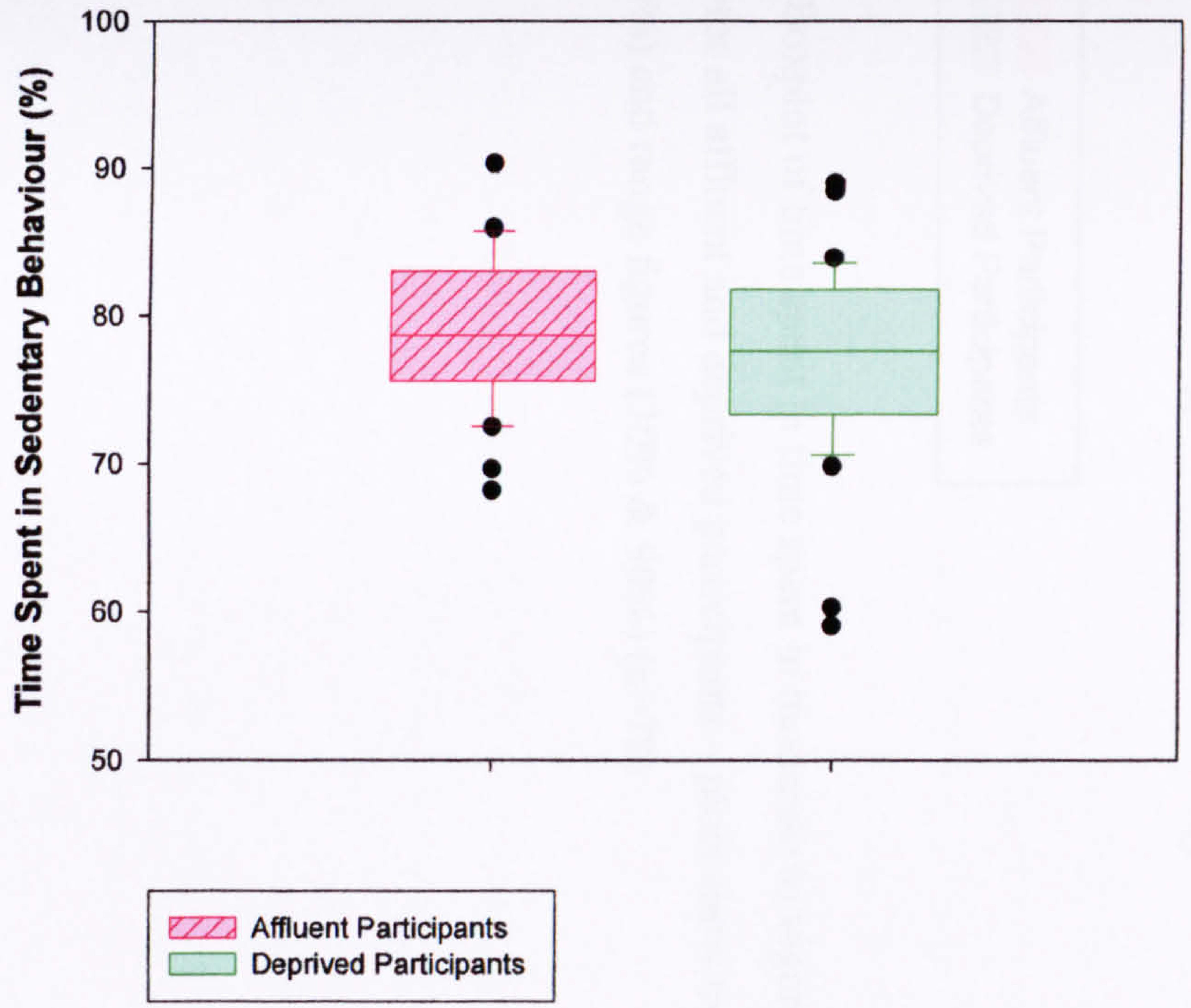


Figure 5.1. Boxplot of time spent in sedentary behaviour (%) for all affluent and deprived participants – plots show median (50%), interquartile (25 % & 50%) and range figures (10% & 90%) (n=78)

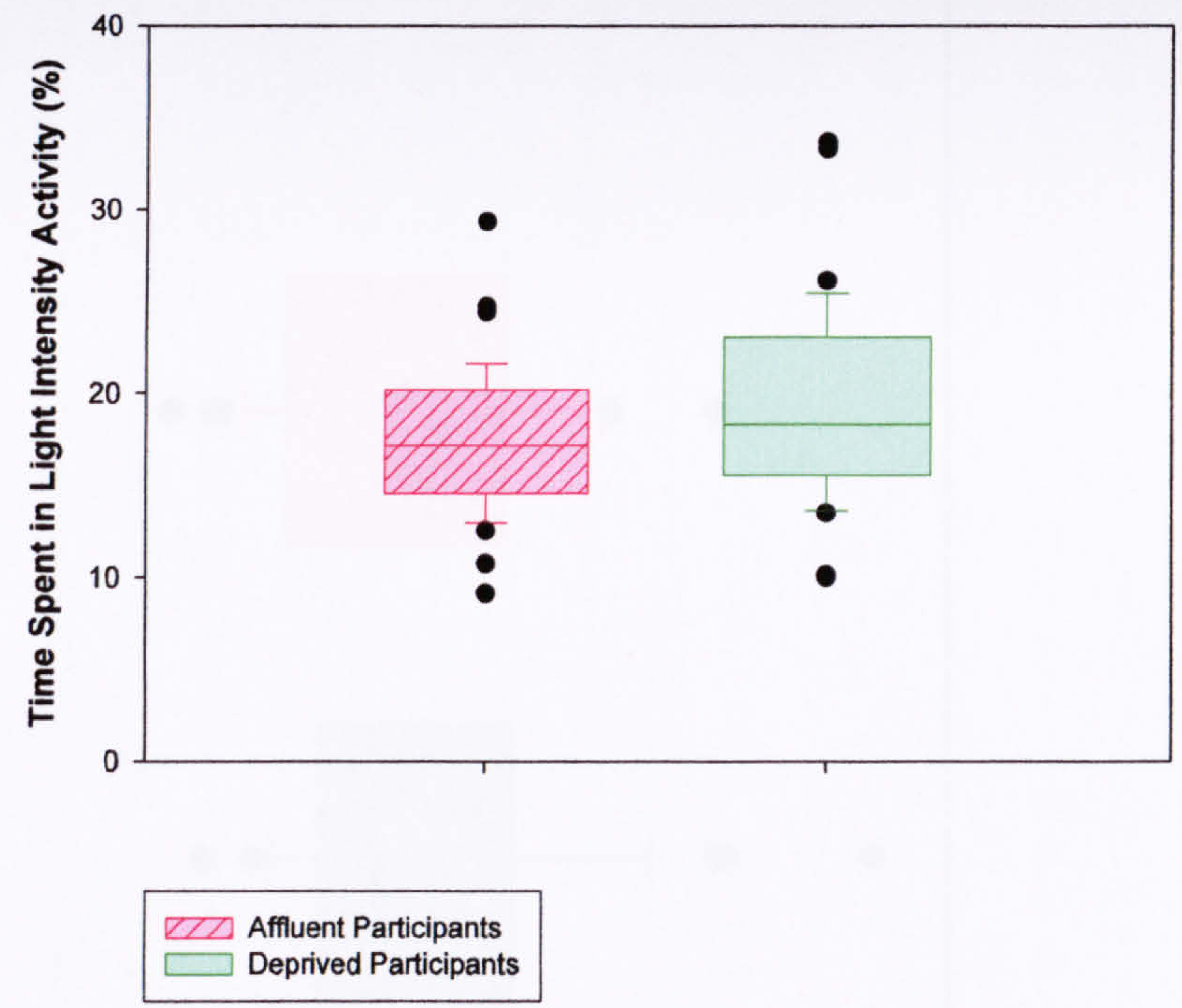


Figure 5.2. Boxplot of time spent in time spent in light intensity physical activity (%)for all affluent and deprived participants – plots show median (50%), interquartile (25 % & 50%) and range figures (10% & 90%) (n=78)

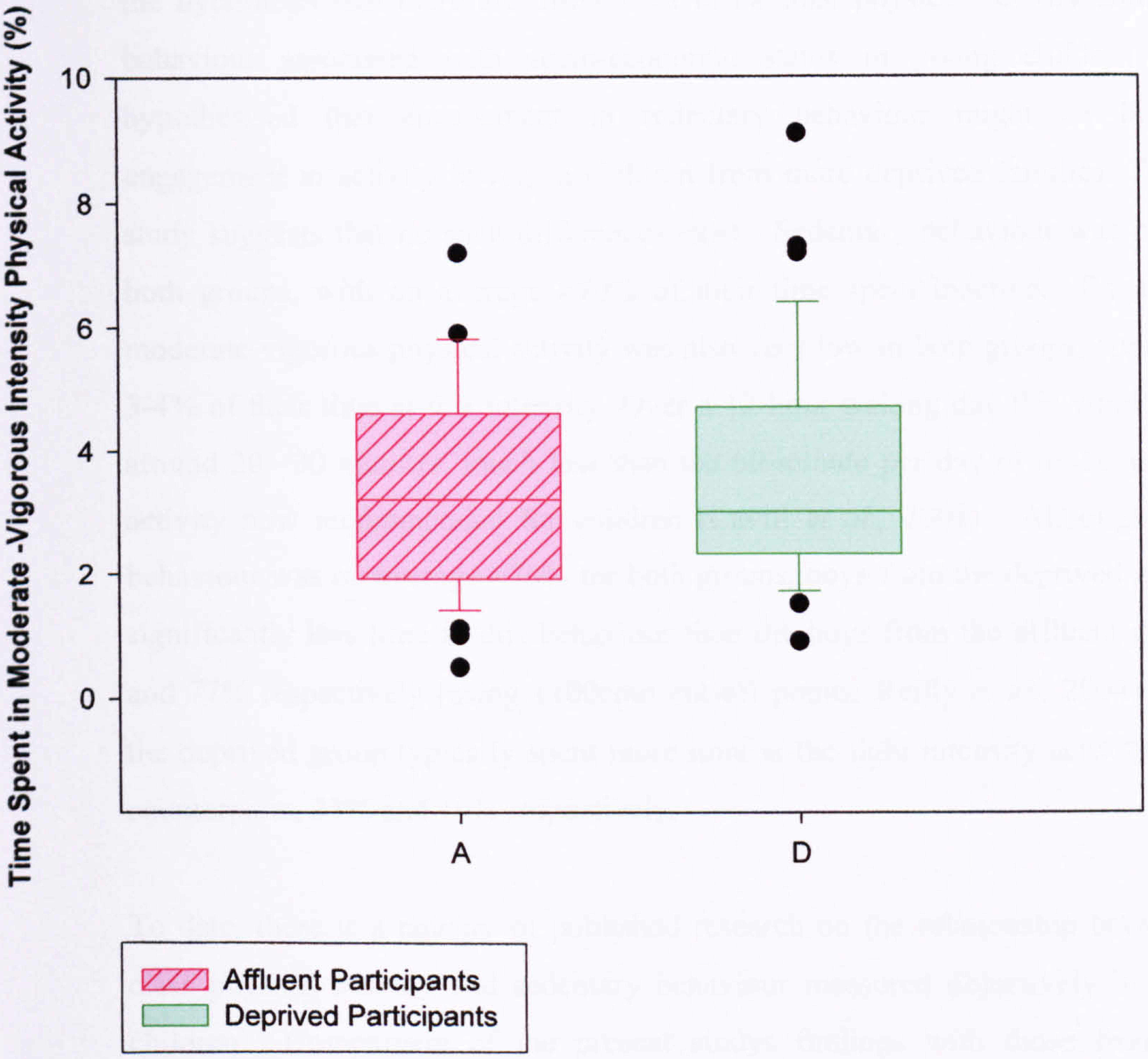


Figure 5.3. Boxplot of time spent in time spent in moderate to vigorous intensity physical activity (%)for all affluent and deprived participants – plots show median (50%), interquartile (25 % & 50%) and range figures (10% & 90%) (n=78)

5.5. Discussion

The present study is believed to be the first attempt to use objective methods to test the hypothesis that there are differences in habitual physical activity and sedentary behaviour associated with socio-economic status in young children. It was hypothesised that engagement in sedentary behaviour might be higher, and engagement in activity lower, in children from more deprived families. The present study suggests that no such differences exist. Sedentary behaviour was common in both groups, with on average >70% of their time spent inactive. Engagement in moderate-vigorous physical activity was also very low in both groups, approximately 3-4% of their time at this intensity. Over a 12-hour waking day this would represent around 20 –30 minutes, much less than the 60-minute per day of moderate-vigorous activity now recommended for children (Cavill *et al.,* 2001). Although sedentary behaviour was on average >70% for both groups, boys from the deprived group spent significantly less time in this behaviour than the boys from the affluent group, 74% and 77% respectively (using 1100cpm cut-off points; Reilly *et al.,* 2004) and hence the deprived group typically spent more time in the light intensity activity than their counterparts, 23% and 19% respectively.

To date, there is a paucity of published research on the relationship between social class physical activity and sedentary behaviour measured objectively in pre-school children. Comparison of the present studys findings with those from previous research is hampered by inconsistent findings, methods of measurement of physical activity and sedentary behaviour (TV viewing as a proxy measure), and the differing size and age of the study populations. No directly comparable published studies were found.

A study conducted by Mallam et al (2003) investigated the contribution of timetabled physical education to total physical activity in primary school children in England. Using MTI/CSA accelerometers the researchers monitored physical activity for 7 consecutive days in 215 children (120 boys) aged 7 – 10.5 years (mean age 9.0) from three schools with different sporting facilities, which had children from very different SES.

The private preparatory school, which had extensive facilities and incorporated 9.0 hours of physical education into the curriculum, the village school which had been awarded for its focus on physical education incorporated 2.2 hours physical education into the curriculum and finally the inner city school, which had limited facilities and offered only 1.8 hours of physical education a week. Results from this study showed that children from the private school were significantly ($p<0.001$) more active in school time than in the village or inner city school. Mallam et al (2003) found no significant difference in total physical activity between the privately educated boys and girls and the inner city school educated boys and girls. They found a statistically significant difference in total physical activity between the private, inner city and the village educated boys, with the village educated boys having a higher total physical activity ($p=0.02$). Mallam et al (2003) also found that boys were more physically active than girls ($p=0.007$).

The Scottish Health Survey (1998) collected data on children aged 2-15 years found no consistent or very strong relationships between physical activity levels and social class. However, they did find some small differences in participation in exercise. Children from higher social class groups participated more in organised sports and exercises than those from the lower social class groups who participated more in walking. However, this study spanned a wider age range (2-15 years age) and was carried out by questionnaire method (parental reports for children under 10 years), which may not be valid especially in the lower age range (Fox and Riddoch, 2000).

Florentio et al (2002) showed conflicting results in a slightly older sample from those reported in this chapter. Data were gathered from 1,208 children aged 8 to 10 years from Manila, Philippines. The children were randomly selected from all public and private schools in the city of Manila. Data were gathered by subjective techniques including interviews and self-administered questionnaires. Results showed there were distinct differences in physical activity patterns between the two groups of children ($p>0.05$). Children from private schools, who were generally of higher SES than those from public schools, were apparently less physically active, were more likely to be driven to school instead of walking, and were more likely to prefer television and computer games over outdoor games (Florentio *et al.*, 2002).

Woodfield et al (2002) examined the relationship of sex, ethnicity, and SES to physical activity levels of 301 US children (mean age 12.9, SD 0.81 years). Physical activity was measured using the four by one day physical activity recall questionnaire (Cale, 1993). In this study, high SES children reported greater levels of physical activity than children from low SES backgrounds.

McVeigh et al (2004) also found conflicting results to those of the present study when they examined the associations between socio-economic status, physical activity, anthropometric and body composition variables in 381 South African children aged 9 years. Physical activity and socio-economic status were assessed via structured retrospective interview taking into consideration all physical activity and sedentary behaviour over the previous 12 months using questionnaires. An asset indicator score was calculated as a proxy measure of socio-economic status and used to divide children into SES quartiles (lowest Q1- Q4 highest).

McVeigh et al (2004) found that children in the highest SES quartile (Q4) had mothers with the highest educational levels, generally came from dual parent homes, were highly physically active, watched less television, weighed more and had greater lean tissue than children in lower quartiles. A greater percentage of children living in dual parent homes and with mothers of a higher educational status were highly active compared with children living in single parent homes and with mothers of a lower educational status. There were higher levels of sedentary behaviour and higher levels of television watching time among the lower SES group (Q1). There were significant racial differences in patterns of activity. White children were found to be more active than black children, more likely to participate in physical education classes at school and watched less television than black children. McVeigh et al (2004) concluded that physical activity levels and socio-economic variables are closely related in this population of South African children. Children with higher SES are more likely to be active and spent less time in sedentary behaviour. However, physical activity and physical inactivity (via television viewing questionnaire) was measured using the subjective method of questionnaires, limitations of which have already been reviewed in chapter 1.

Engagement in sedentary behaviour is one of the few reasonably well-established risk factors for obesity in childhood (Dietz, 1996; Robinson, 1999). As previously mentioned in chapter 1, TV viewing is a proxy method for assessing sedentary behaviour in young children. Previous published data on the association between TV viewing and social status has found a negative relationship between sedentary behaviour and SES (Müller *et al.*, 1999; Grund *et al.*, 2001). In the present study, sedentary behaviour did not differ significantly between socio-economic groups in girls ($p>0.05$), and in the boys there was a slightly but significantly lower engagement in sedentary behaviour in the affluent group, who are at lower obesity risk.

The present study found no differences in physical activity or sedentary behaviour associated with SES in the girls, and some evidence of slightly higher physical activity levels in the boys, suggest that the cause of the marked difference in obesity risk (in this age group) associated with socio-economic status is more likely to be related to the other side of the energy balance equation, i.e. energy intake, especially in the lower social class groups (James and Nelson, 1997; Müller *et al.*, 1999). Further studies of dietary differences and SES are needed to address this question. Currently measurements of energy intake in children, as in adults, are neither very precise nor accurate in free-living children (Reilly *et al.*, 1998; Reilly *et al.*, 2001). Hypothesis testing in relation to the causes of energy balance is probably best carried out by measuring physical activity since this variable could be measured with greater confidence (Reilly *et al.*, 2001). Further studies with larger samples and objective measures of physical activity and sedentary behaviour are needed to further address this question

In spite of the documented negative associations between low SES and PA in children, the mechanism by which this occurs is not well understood. In this group of children, it appears that physical activity patterns could either be regulated by the primary caregiver or by the school that the child attends. If the school does not provide PE classes or after-school sport, parental or caregiver support may act as a buffer. If the parent or caregiver provides the support, their SES circumstances would be an influential factor.

Being born into a particular social class cannot itself 'cause' obesity, but characteristics of socio-economic groups related to material circumstances and behaviour or knowledge, which ultimately influence energy balance, might. Attitudes towards obesity in developed societies however, may provide some explanation of the relationship to social class (Sobal and Stunkard, 1989).

Failure to observe differences in the 'expected' direction could relate to lack of power, but the power calculation suggested that the study was powered to detect very small differences between the affluent and deprived groups. No suggestion of differences consistent with the hypothesis that engagement in physical activity was lower in the children of poorer families was found. The cut-offs applied to accelerometry output have been validated against energy expenditure in children (Puyau *et al.,* 2002). However, a major limitation in the Puyau et al (2002) study was that the cut-offs were validated using only 26 subjects, (6-16 years old) who were older than the subjects used in this study. Recent unpublished research by Penpraze et al (2004) suggests that age may not greatly influence the validity of the cut-offs across the age range 4 - 11 years. Association between physical activity, sedentary behaviour and SES may also change with age. Thus it is possible that larger differences may emerge in later childhood.

It is possible that subtle differences in the types of activity undertaken by children in different socio-economic groups (The Scottish Health Survey, 1998), not measured by accelerometry, might be associated either with differences in energy expenditure or the tendency to eat/snack while inactive (Robinson, 1999; Reilly and McDowell, 2003). An activity undertaken by most of the children from the affluent group was swimming; unfortunately this could not be measured via the MTI/CSA and therefore could have led to a very small under estimation of total physical activity and time spent in different activity intensities. However, one can speculate that time spent swimming at age 5 years is minimal and therefore would not contribute a great deal to the over all physical activity level of the young child. Until there are further developments in technology, this limitation in the MTI/CSA is unavoidable when investigations on free-living subjects are carried.

The accelerometer used in the present study was uniaxial (is designed to measure activity predominantly in the vertical plane). While in theory measurement in two or three planes of movement might provide greater accuracy, empirical studies comparing uniaxial vs. bi or triaxial accelerometry, do not bear this out (Welk *et al.*, 1995; Puyau *et al.*, 2002; Kelly *et al.*, 2003), and it is likely that there is a substantial vertical component to most young children's movements. As previously mentioned in chapters 3 and 4, physical activity and sedentary behaviour data were collected using 1-minute measurement intervals. In theory, shorter measurement intervals might provide more accurate quantification of more vigorous activities, (Nilsson *et al.*, 2001; Nilsson *et al.*, 2002; Puyau *et al.*, 2002). The empirical evidence does not substantiate this and suggests that the main practical consequence of using 1 minute epochs in children is a misclassification of some vigorous activity as moderate intensity activity (Nilsson *et al.*, 2002).

The sampling interval (epoch) of accelerometer is often set to 60 seconds and summarises all registered counts during this time. Nilsson et al (2002) reported no significant difference in time spent at low and moderate intensity when reintegrating the epoch interval from 5- to 10-, 20-, 40- and 60-second intervals. However, at vigorous intensities the shorter bursts of vigorous activity, inducing high activity counts, might be blunted when summed over one whole minute. If the children only spend a little time in vigorous activity, the actual time will probably be undetected since the activity must consist of either many short bursts of extremely intensity combined with low activity, or intense steady-state activity (e.g. running) to be registered with 60-second sampling interval (Nilsson *et al.*, 2002). The relevance of this circumstance, especially for the analysis of activity pattern among children needs to be better clarified, possibly with validated cut-offs specific to this age group. These age specific cut-offs (would possibly allow interpretations of accelerometer output) are *not* available for shorter measurement periods; even if they were available they might not be practical (Puyau *et al.*, 2002).

However, as the present study shows children of this age spend most of their time in sedentary behaviour regardless of their SES, and the 60-second epochs were probably adequate for the present study. A further limitation of the present study was the use of the Carstairs deprivation score to assess SES. As previously discussed in chapter 2, the depcat score has some limitations but the alternative methods of are equally as crude.

5.6. Conclusion

In conclusion, the present study found low levels of engagement in moderate-vigorous physical activity, and high engagement in sedentary behaviour in modern 5 year olds regardless of socio-economic status. The very low levels of engagement in moderate-vigorous physical activity in these young children should give serious cause for public health concern. Differences between children from affluent or deprived families were not consistent with the hypothesis that differences in physical activity or sedentary behaviour underlie socio-economic variations in obesity risk. This study suggests that alternative explanations should be sought for the socio-economic disparity in childhood obesity risk. The present study showed that SES had no effect on habitual physical activity and sedentary behaviour in young Glaswegian children. However, given the exploratory nature of the present study it is important that the study be replicated in other samples and settings.

Chapter 6: Habitual Physical Activity And Sedentary Behaviour In Young Irish Rural Children Versus Scottish Urban Children

6.1. General Introduction

Low physical activity levels and high levels of sedentary behaviour may now be characteristic of British pre-school children (Reilly *et al.*, 2004) and there is recent evidence of surprisingly high engagement in TV viewing in US pre-school children (Certain and Kahn, 1998). Good data on objectively measured physical activity levels of Irish and European children are lacking (Livingstone *et al.*, 2001; Livingstone *et al.*, 2003).

In order to develop effective intervention programmes to promote physical activity and decrease sedentary behaviour, the variables that significantly influence physical activity in young children need to be identified (Sallis *et al.*, 2000; Fulton *et al.*, 2001). Correlates of physical activity and sedentary behaviour in young children remain unclear. In a recent review of correlates of physical activity, Sallis et al (2000) argued that inconsistent evidence exists regarding environment and its association with physical activity and sedentary behaviour (Sallis *et al.*, 2000). Sallis et al suggested that this variable should be studied in more detail (Sallis *et al.*, 2000). In an attempt to provide further evidence in this area, this study attempted to examine urban versus rural differences in physical activity levels in a homogenous sample of primary school children.

In the present study, it was hypothesised that children from rural backgrounds might be less sedentary and more physically active than children from urban backgrounds. It has been speculated that urban children are "imprisoned by their environment" and that this environment is restrictive for MVPA.

Recent data have shown young Scottish urban children to be inactive (Jackson *et al.*, 2003; Reilly *et al.*, 2004; Montgomery *et al.*, 2004). Romero et al (2001) suggest a possible explanation for dramatic increase in sedentary behaviour in young urban children is the increased likelihood that they are driven to school instead of walking, and are more likely to prefer television and computer games over outdoor games.

6.1.2. Obesity Prevalence In Ireland

Data from the North/South Ireland Food Consumption 2001Survey (McCarthy *et al.*, 2002) showed that 42% of the Irish population were in the normal weight range (BMI 20-24.9). A total of 18% of adults were classed as obese (defined as BMI >30: 20% of men and 16% of women) while 39% were overweight (BMI 25-29.9: 46% of men and 33% of women). Since 1990, the prevalence of obesity has increased by 67% in women from 13% to 16% and in men from 8% to 20%. It is likely that Ireland has been affected by the obesity epidemic in much the same way as the rest of Northern Europe (McCarthy *et al.*, 2002).

Unfortunately there is to date, no data on the prevalence of overweight/obesity in young people in Ireland. While there is currently a nutrition survey of young people in Ireland being set up by researchers in University College Cork and Trinity College Dublin, no data have yet been reported.

6.1.3. Physical Activity Levels In Ireland

During the course of the last century, changes in Irish lifestyles have had a profound impact on patterns of energy expenditure and physical activity. Increased mechanisation in the workplace has markedly reduced the need for moderate to vigorous occupational physical activity, to the extent that >80% of men and >90% of women are now engaged in sedentary occupations (Livingstone *et al.*, 2001). In the home, the energy cost of housework has also been minimised while television viewing and related pursuits now monopolise much of the leisure time of a significant proportion of the population (Livingstone *et al.*, 2001).

As a result of this modern technology and increased affluence, predominantly sedentary populations can achieve energy equilibrium at a level of energy expenditure below that considered optimal for health. A recent study by Livingstone et al (2001) conducted on a nationally representative sample of Irish adults (n=1379) aged 18-64 years, reported men to be twice as active in work and recreational activity (139.7 sd 83.9 METS per week) as women (68.5 sd 58.7 METS per week; P<0.001). However, women were three times more active in household tasks (65.9 sd 58.7 METS per week vs. 22.6 METS per week; P<0.001). Overall levels of physical activity declined with increasing age, particularly leisure activity in men.

Two baseline surveys of health related behaviour among adults and school children were carried out across the Republic of Ireland in 1998 and again in 2002. The results of these two cross sectional studies SLÁN (Survey of Lifestyles, Attitudes and Nutrition) adults aged 18+ years (n=5992) and HBSC (Health Behaviours in school-aged children, school-going children aged 10-17 years (n=5712). These results reported that overall just over half of the 5992 adults (51%) surveyed by questionnaire reported participated in some form of physical activity compared with 52% in 1998 (The National Health & Lifestyle Surveys, 2002).

To date there are no published reports on physical activity in Irish children, particularly young children, but it is widely assumed that activity levels must have fallen in recent years and that modern Irish children may have physically inactive lifestyles (O'Sullivan, 2002). A questionnaire based study in 1989 of fitness and activity levels in 10-13 year old Irish children found that one third of the sample exercised four or more times a week. Only 23% walked or cycled to school (Watson and Drummy, 1993). Similarly, a questionnaire based study by Hussey et al (2001) in children aged 7-9 years (n=786, 352 boys and 434 girls) found that only 39% of children were participating in vigorous exercise for at least 20 minutes three or more times a week, with fewer girls (28%) than boys (53%) meeting this target. A further 57% of children were engaging in at least 20 minutes of light exercise three or more times a week, with no differences between the sexes. Most of the children (78%) reported spending one to three hours a day watching T.V.

The study concluded that despite the limitations of using questionnaires a worrying number of Dublin school children (14% boys and 24% girls) were not performing a volume of physical activity considered necessary to benefit the cardiovascular system. The study also reported that boys were more significantly active than girls (Hussey *et al.,* 2001).

A large questionnaire based study conducted by O'Sullivan (2002) collected physical activity data from 1,602 Irish school children aged 11-12 years. It reported that 84% of children reported participating in some form of physical activity four or more times a week outside of school. Only 4.2% of the children were classified as inactive, exercising only once a week or less. Gender differences in recreational activity were significant with boys being more active than girls ($P<0.001$). There were no significant differences in physical activity between social class groups, whether boys and girls were analysed separately or together. The study also reported that children were significantly more active in the summer period (May–June) rather than the autumn period (September). However, data on physical activity were collected by questionnaire, so the accuracy of the results is questionable (Welk *et al.,* 2000a; Shephard, 2002).

The National Health and Lifestyle Study (INHLS, 2002) (n= 5712) reported similar findings to O'Sullivan's study. Irish Children were asked about their participation in exercise outside of class time. They were asked about the frequency with which they exercised so much that they were sweating or out of breath. Overall, 48% of children reported exercising four or more times per week while 12% reported exercising less than weekly. However, this masks some substantial gender differences. Although only 8% of boys and 14% of girls reported exercising less than weekly, 59% of boys and 38% of girls reported exercising four or more times a week. Although there are few differences across social class, exercise participation was reported to decrease with age through childhood. The National Health and Lifestyle Study (2002) reported that "exercising four or more times per week" decreased from 59% of 10-11 year olds and 53% of 12-14year olds to 35% of 15-17 year olds. This decrease was apparent in both boys and girls but was particularly noticeable among girls, dropping from 55% of 10-11 year olds, through 44% of 12-14 year olds to 25% of 15-17 year olds.

Among school-going children, vigorous exercise rates were higher among boys than girls at all ages but in 1989 the gender gap doubled by the age 15-17 with a marked increase in the number of girls reporting no activity at all. There was a slight fall compared to 1989 and no discernible social class trend for boys (The National Health and Lifestyle Study, 2002). Physical activity rates were lower than for boys and as in 1989 showed a very sharp drop by the age of 15 (Figure 6.1a in appendix).

While both the O'Sullivan (2002) and The National Health and Lifestyle Study (2002) reported on exercise of young children, neither study considered objectively measured physical activity in children, or unstructured physical activity as distinct from exercise

6.1.5. Physical Activity Levels Of Scottish And UK Children

In addition to the paucity of physical activity data in Irish children, only a limited number of studies have reported on objectively measured physical activity and patterns of activity of UK children. To date there have been few studies which have objectively looked at physical activity in young children aged 5 years or younger. Two recent studies have reported physical activity objectively in young urban/suburban Scottish children (Jackson *et al.*, 2003; Reilly *et al.*, 2004).

Jackson et al (2003) described physical activity using the MTI/CSA accelerometer in a representative sample of preschool children. Physical activity was measured over three days (two week days and one weekend day) in 104 children, 52 boys, and aged 3-4 years. The results of the Jackson et al (2002) study showed that mean total activity at baseline was 777cpm (SD 207) in boys and 657cpm (SD 172) for girls, a significant gender difference ($p<0.001$). Jackson et al (2003) suggested that total physical activity increases during the school period in Scottish children and that gender differences in total activity are present in early life and are maintained at least over the period studied (Jackson *et al.*, 2003).

Reilly et al (2004) tested the hypothesis that levels of total energy expenditure and physical activity are low in modern 3-5 year olds. Doubly labelled water was used to measure TEE while physical activity was measured by accelerometry in a representative sample of urban/suburban Glaswegian children (n=78 at age 3, n=72 at age 5). Mean physical activity level (PAL; TEE/resting energy expenditure) was 1.56 (SD 0.39) at age 3, and 1.61 (SD 0.22) at age 5. Median time in sedentary behaviour was 79% at age 3 (range 63-93%) and 76% (range 61-92%) at age 5. Median time spent in moderate-vigorous physical activity represented only 2% of waking hours at age 3 and 4% at age 5. Reilly et al (2004) suggests that modern children have a sedentary lifestyle that is already evident before the age of school entry. Most would fail to meet current recommendations for moderate-vigorous physical activity in childhood, and even fail to meet recommendations for moderate-vigorous activity in adults. The study provides a possible explanation as to why obesity risk is so high for young British children with a sedentary lifestyle established from an early age.

6.2. Aims Of The Present Study

A recent review by Fulton et al (2001) for the US Centers for Disease Control and Prevention hypothesised that environmental factors might indirectly affect physical activity behaviour. As previously mentioned, studies investigating young children's physical activity and sedentary behaviour in children have predominately been carried out in urban/inner-city communities (Hussey *et al.*, 2001; Metcalf *et al.*, 2002; Trost *et al.*, 2002; Jackson *et al.*, 2003; Reilly *et al.*, 2004). Consequently, it is not known to what extent these findings are generalisable to children living in rural communities. It is widely believed that children from rural backgrounds are more active than their peers from urban backgrounds. To test the hypothesis that rural children are more physically active than their urban peers, children from urban Scotland (Glasgow) (reported in chapter 5) were pair matched with children from rural Ireland (Co. Carlow) for sex, age, social class, and time of year measured. All children were measured during term time, out with school holidays.

6.3. Methods

6.3.1. Recruitment Of Irish Rural Subjects

The subjects were healthy rural Irish children recruited in 2003. A list of national primary schools in County Carlow, Ireland was obtained from the Carlow County Council. The list consisted of 42 schools suitable for inclusion (excluding urban schools and schools for children with special needs). The Head Teacher of each school (n=42) was contacted by mail with a detailed explanation of the study. Written consent was obtained from 8 rural schools willing to participate in the study. Recruitment letters (detailing the study in full) and consent forms for all parents of the 212 children in Junior Infants were sent to the school. A total of 53 families consented to participate in the study, 41 subjects were included in the final analysis. Twelve participants were excluded from the study due to their absence at time of measurement (n=9), technical difficulties with the accelerometer (n=2), and refusal to wear the accelerometer (n=1). Measurements of BMI, habitual physical activity and sedentary behaviour by accelerometry were carried out in these 41 subjects.

6.3.2. Recruitment Of Scottish Urban Subjects

Scottish urban subjects were recruited in the same manner as previously described in chapter 5. Six schools in Glasgow, Scotland consented to the study, 360 subjects were invited to participate, and 116 families consented (as described in chapter 5). Forty-one subjects (20 boys and 21 girls) were selected to pair match with the Irish rural participants. Subjects from the Scottish urban group were matched for gender, age, season, time of measurement (during school term) and social class (occupationally defined) with participants from the Irish rural group. The local Ethics Committee approved the study. Informed written consent was obtained by the parent/guardian of each child.

6.3.3. Design And Power

The present study recruited children from rural Southern Ireland (Carlow) and urban West of Scotland (Glasgow) pair matched for age, gender, and time of measurement (for season, school days/school holidays) and socio-economic status (SES). Children from Ireland and the West of Scotland share a common genetic/cultural background, with many families from rural Ireland immigrating to Scotland in the past. The paired design was intended to reduce the influence of factors other than urban or rural environment between the two groups, and increase study power. Paired studies with as few as 20 well matched pairs have been adequate to detect the origin of subtle differences in obesity risk between other groups (Reilly *et al.,* 1998; Kelly *et al.,* 2005).

It was estimated that a mean difference in total physical activity of around 100 accelerometry counts per minute day between groups, (representing a difference of 10-15% between the groups i.e. 100cpm is approximately 10-15% of our typical activity level of 600-800cpm (Jackson *et al.,* 2003; Montgomery et al., 2004; Reilly et *al.,* 2004), would be detectable with 90% power at significance 0.05, with approximately 40 children in each group (i.e 40 rural Irish children and 40 urban Scotish children).

6.3.4. Other Measurements

BMI was calculated as previously described in Chapter 3, and these measurements were used for descriptive purposes only. Social class was assessed by classifying all participants using the UK Standard Occupational Classification of the Office of Population Census and Surveys (OPCS, 1991) and the Central Statistics Office Census 96 Occupations of the Republic of Ireland (CSO, 1998). As the Irish system of classification social class was re-modelled using the UK system (CSO, 1998), pairing of 41 rural Irish and 41 urban Scottish children for the present study was relatively straightforward. Due to the similarities between the two systems of classification the OPCS system was adopted for all participants in this study.

6.3.5. Measurement Of Physical Activity And Sedentary Behaviour

Physical activity and sedentary behaviour were measured objectively using the MTI/CSA WAM-7164 (accelerometer MTI, Shalimar, Florida). In advance of the study, it was decided that satisfactory adherence to this measurement protocol would have been attained if families recorded physical activity/sedentary behaviour for a minimum of 6 hours per day (approximately 60% of the waking hours for children of this age; Iglowstein *et al.,* 2003), for a minimum of 5 days. Total physical activity was expressed as counts per minute averaged over the monitoring time. Sedentary behaviour and patterns of physical activity were assessed using established cut-offs (Puyau *et al.,* 2002; Reilly *et al.,* 2003).

6.3.6 Characteristics Of Rural Area In Ireland

County Carlow is the second smallest county in the south east of Ireland. It is a small agricultural county situated in the south east of the Republic of Ireland. The county consists of 89,790 hectares in total and has a population of 46,044 (Central Statistics office, 2002). Carlow was chosen as the rural population due to the ease of access to schools in this area and because it has been clearly defined as a rural area. Table 6.1 shows the breakdown in the population of the county based on the 2002 National Census.

Table 6.1: Characteristics of Population of Carlow, Republic of Ireland

	Population	Males	Females
Carlow County	46,014	23,403	22,611
Carlow Town	26,436	12,980	13,456
Carlow Rural	19,576	10,423	9,153

6.3.7. Statistical Analyses

Using the statistical package Minitab 13.3, all data were checked for normality prior to statistical analysis using descriptive statistics, histograms with normal distribution curves and using Anderson-Darling (A.D) tests of normality. Group anthropometric characteristics and physical activity/sedentary behaviour patterns of the 41 Irish rural and the 41 Scottish urban subjects were described using basic descriptive statistics. As the group data were skewed, Mann-Whitney U test (unpaired) were used to test the significance of any differences in anthropometric characteristics, engagement in physical activity or sedentary behaviour between the 41 Irish rural and the 41 Scottish urban subjects. For the paired analyses Wilcoxon signed ranked test (paired) were used to compare one rural Irish child (e.g. girl) to one Scottish urban child (e.g. girls). Gender analyses were also carried out. The SES distributions of the studies sample were compared with that of Carlow, Ireland and the city of Glasgow, Scotland using a chi-squared test to ensure they were repsesnetative in terms of SES.

6.4. Results

6.4.1. Characteristics Of Irish Rural Subjects

Anderson-Darling normality testing showed skeweness in the pooled data for age (yrs), height (M), Weight (kg), BMI and BMI SDS. The characteristics of the 41 (median age 5.4 range 4.3 – 6.0) subjects are shown in table 6.3. Boys and girls did not differ significantly for age (Mann-Whitney U test, $p = 0.21$), weight (Mann-Whitney U test, $p = 0.57$), height (Mann-Whitney U test, $p = 0.51$), BMI (Mann-Whitney U test, $p = 0.96$), or BMI SDS (Mann-Whitney U test, $p = 0.78$), relative to UK 1990 reference data (an index of under and overweight). Characteristics of subjects, including time spent in sedentary behaviour and activities of different intensity are shown in Tables 6.3 and 6.4. Subjects were broadly representative of Carlow, Ireland in terms of socio-economic status ($X^2 > 0.05$).

6.4.2. Characteristics Of Scottish Urban Subjects

Anderson-Darling normality testing showed skeweness in the pooled data for age (yrs), height (M), and Weight (kg). The characteristics of the 41 (median age 5.5 range 4.9, 6.4) subjects are shown in table 6.3. Anderson-Darling normality testing showed skeweness in the pooled data for age (yrs), Weight (kg), BMI, and BMI standard deviation score. Boys and girls did not differ significantly for age (Mann-Whitney U test, $p = 0.30$), weight (Mann-Whitney U test, $p = 1.00$), height (Mann-Whitney U test, $p = 0.79$), BMI (Mann-Whitney U test, $p = 0.96$), or BMI SDS (Mann-Whitney U test, $p = 0.42$), relative to UK 1990 reference data (an index of under and overweight). Characteristics of participants, including time spent in sedentary behaviour and activities of different intensity are shown in Tables 6.3 and 6.4. Subjects were broadly representative of Glasgow, Scotland in terms of socio-economic status (X^2. > 0.05).

6.4.3. Duration Of Monitoring Of Irish Rural Children

Median duration of activity monitoring in the 41 Irish rural children over the 7-day period was 76.2 hours (range 42.2, 83.8 hrs) and all of the 41 children provided a minimum of 5 days of activity monitoring data with at least 8 hours per day (Table 6.3). Median duration of activity monitoring in the boys was 74.9 hours (range 42.2 - 83.7 hrs), and 77.1 hours (range 58.3 - 83.8 hrs) for the girls. There were no significant differences in the duration of activity monitoring between the boys and the girls (Mann-Whitney U test, p= 0.1709; 95% CI = (-10.5 - 1.4 hrs).

6.4.4 Duration Of Monitoring Of Scottish Urban Children

Median duration of activity monitoring in the 41 Scottish urban children over the 7-day period was 75.1 hours (range 46.7 - 91.2hrs) and all of the 41 children provided at minimum of 5 days of activity monitoring data with a minimum of 8 hours per day (Table 6.3). Median duration of activity monitoring in the boys was 75.6 hours (range 46.8 - 89.0 hrs), and 74.4 hours (range 46.7 - 91.2hrs) for the girls. There were no significant differences in the duration of activity monitoring between the boys and the girls (Mann-Whitney U test, p= 0.3682; 95% CI = -12.6, 4.1 hrs).

6.4.5. Differences In Time Spent In *Total* Physical Activity

Total physical activity was expressed as accelerometry counts per minute (cpm), summarised over the entire recording period. This did not differ significantly between pairs for rural Irish and urban Scottish participants. Median accelerometry cpm in the Irish rural participants was 726 cpm (range 395 - 1287 cpm) and 762cpm (477 - 1062 cpm) for the Scottish group (Wilcoxon signed ranked test, $p = 0.61$; Table 6.3). There were also no statistically significant differences in total physical activity between Irish rural and Scottish urban children when considered separately by gender (Wilcoxon signed ranked test, $p > 0.05$; Table 6.4).

6.4.6. Differences In Time Spent In *Light Intensity* Physical Activity

Median time spent in light intensity activity was not significantly different for the two groups (Irish rural children, 19% (range 10-24) vs. 18% (range 10-26) for the Scottish urban children; Wilcoxon signed ranked test, $p = 0.82$; Table 6.3). There were no statistically significant differences in light intensity physical activity between Irish rural and Scottish urban children when considered separately by gender (Wilcoxon signed ranked test, $p > 0.05$; Table 6.4).

6.4.7. Differences In Time Spent In *Moderate - Vigorous* Physical Activity

Median time spent in moderate to vigorous intensity activity (MVPA) was identical between the Irish rural and the Scottish urban groups: 3% (range 0-8) vs. 3% (range 1-9), Table 6.3. There were significant differences when data were analysed separately by gender. Table 6.4.

6.4.8. Differences In Time Spent In *Sedentary Behaviour*

Median time spent in sedentary behaviour was similar between the Irish rural and the Scottish urban groups: 78% (range 53-89) vs. 79% (range 67-89) (Wilcoxon signed ranked test, $p = 0.83$; Table 6.3). There were no statistically significant differences in sedentary behaviour between Irish rural and Scottish urban children when considered separately by gender (Wilcoxon signed ranked test, $p > 0.05$; Table 6.4).

Table 6.2. Characteristics Of Subjects (N = 82; Median And Range).

Variable	Rural Irish (n= 41)	Urban Scottish (n= 41)	95% Confidence Interval	p value[2]
Age (years)	5.4 (5.1, 5.7)	5.5 (5.3, 5.9)	(-4.0, 0.0)	0.063
Weight (kg)+	21.8 (14.7, 31.0)	20.3 (15.3, 32.9)	(-0.2, 3.0)	0.032*
Height (m)	1.13 (1.01, 1.21)	1.10 (1.00, 1.40)	(-0.05, 0.02)	0.307
BMI (kg/m^2)	17.1 (16.1, 18.9)	15.8 (14.9, 17.1)	(0.6, 2.0)	0.001*
BMI SDS[1]	1.0 (0.4, 1.9)	0.2 (-0.4, 0.9)	(0.4, 1.3)	0.000*

[1]SDS – standard deviation score relative to UK 1990 reference data, [2]p value – obtained on performing Mann-Whitney tests for difference between rural and urban children, * indicates significant difference between rural and urban children.

Table 6.3. Physical Activity And Sedentary Behaviour Of Participants (N = 82; Median And Range).

Variable	Rural Irish (n= 41)	Urban Scottish (n= 41)	95% Confidence Interval	p value[2]
Total Hours Monitored	76.2 (42.2, 83.8)	75.1 (46.7, 91.2)	(-5.2, 3.5)	0.626
Total Physical Activity (cpm[1])	726 (395, 1287)	762 (477, 1062)	(-96, 51)	0.610
% Time in Light Intensity Activity[2]	18.8 (9.9, 39.9)	18.3 (10.0, 25.8	(-1.7, 2.1)	0.824
% Time in MVPA[3]	3.0 (0.7, 8.2)	2.8 (0.8, 8.5)	(-0.8, 0.6)	0.893
% Time in Sedentary Behaviour[4]	77.6 (53.0, 89.3)	78.7 (66.8, 88.5)	(-2.8, 2.2)	0.834

[1]cpm – counts per minute, [2]percent of time spent in light intensity activity, [3]%MVPA – percent time spent in moderate and vigorous physical activity, [4]percentage of time spent in sedentary behaviour, [5]P value – obtained on performing Wilcoxon signed ranked test for difference between rural and urban children, * indicates significant difference between rural and urban children.

Table 6.4 Comparisons Of Physical Activity Intensities For Irish Rural And Scottish Urban Children By Gender

Variable		Irish Boys (n=20)	Scottish Boys (n=20)	Irish Girls (n=21)	Scottish Girls (n=21)
Total Hours Monitored	Median	74.9 (42.2, 83.7)	75.6 (46.8, 89.0)	77.1 (58.3, 83.8)	74.4 (46.7 , 91.2)
	95% CI for difference	(-9.9, 6.6)		(-5.9, 6.0)	
	p value[5]	0.940		0.911	
Total Activity (cpm)[1]	Median	834 (490, 1287)	787 (477, 918)	628 (395, 823)	722 (482 , 1062)
	95% CI for difference	(-64, 183)		(-208, 15)	
	p value[5]	0.360		0.118	
% Time in Light Intensity Activity[2]	Median	20.3 (12.1, 39.9)	18.5 (12.3, 24.5)	15.8 (9.9, 23.5)	17.9 (10.0 , 25.8)
	95% CI for difference	(-0.50, 4.45)		(-4.00, 1.20)	
	p value[5]	0.097		0.366	
% Time in MVPA[3]	Median	4.2 (1.0, 8.2)	3.5 (0.8, 6.0)	2.2 (0.7, 5.7)	3.0 (1.0 , 8.0)
	95% CI for difference	(-0.50, 2.40)		(-2.20, 0.50)	
	p value[5]	0.204		0.140	
% Time in Sedentary Behaviour[4]	Median	74.4 (53.0,86.8)	77.0 (71.4, 86.9)	81.9 (74.3, 89.3)	79.9 (66.8 , 88.5)
	95% CI for difference	(-6.55, 0.75)		(-1.55, 5.80)	
	p value[5]	0.121		0.192	

[1]cpm – counts per minute, [2]percent of time spent in light intensity activity, [3]%MVPA – percent time spent in moderate and vigorous physical activity, [4]percentage of time spent in sedentary behaviour, [5]P value – obtained on performing Wilcoxon signed ranked tests for difference between rural and urban children, *indicates significant difference between rural and urban children

6.5. Discussion

The present study hypothesised that time spent in sedentary behaviour might be greater, and engagement in physical activity lower, in children from urban families. The present study used objective methods to test the hypothesis that there are differences in habitual physical activity and sedentary behaviour in young children living in two very different environments. Our previous studies of urban Scottish children using the same methods (Jackson *et al.,* 2003; Montgomery *et al.,* 2004; Reilly *et al.,* 2004; Kelly *et al.,* 2005) found very low levels of habitual physical activity and high levels of sedentary behaviour. Perhaps surprisingly, in the present study children from the two environments were very similar in terms of their physical activity: sedentary behaviour was common in both rural and urban groups, and engagement in moderate-vigorous physical activity low. On average, time spent in moderate-vigorous activity represented only around 3-4% of the waking hours. Over a 12-13 hour waking day, this would represent around 19-25 minutes of MVPA, much less than the 60-minute per day now recommended for children (Cavill *et al.,* 2001). Comparison of the present studies findings with those from previous research is hampered by methods of measurement of physical activity and sedentary behaviour (TV viewing as a proxy measure) and the definitions of physical activity, and the differing size and age of the study populations. No directly comparable published studies were found.

Irish rural children in the present study (n=41) demonstrated very low levels of physical activity with a group median accelerometry cpm of 726cpm (range 395, 1287cpm, which is well below the 1100 cpm cut-off used to define sedentary behaviour. Of the monitored time, 78% was spent in sedentary behaviour, 19% in light intensity physical activity, and only 3% of the monitored day in moderate to vigorous intensity activity. The O'Sullivan (2002) study reported conflicting results to those of the present study. O'Sullivan reported that Irish children appeared to spend less time "inactive" than those recorded for other European populations. They reported that demographic, social and cultural factors contribute to a highly active young population in Ireland. The study also reported a high percentage of active and highly active children among rural children (O'Sullivan 2002).

However, physical activity was measured using questionnaires and as previously mentioned in chapter 2, over-reporting is a common limitation (Montoye *et al.*, 1996). Hussey et al (2001) reported high levels of sedentary behaviour measured by questionnaire in 786 urban Irish children aged 7-9 years. Results showed 39% of children participated in vigorous activity for at least 20 minutes three or more times a week and 78% of children spent three or more hours a day (sedentary) watching TV.

Scottish urban children in the present study (n=41) also demonstrated very low levels of physical activity, with a group median of 762cpm (range 477 - 1062cpm). Scottish urban children spent in this sample spent 79% of their waking time in sedentary behaviour. Eighteen percent of the monitored time was spent engaged in light intensity physical activity, and only 3% of the monitored day in moderate to vigorous intensity activity. Objectively measured data on physical and sedentary behaviour patterns of Scottish children to date are very sparse. Two recent studies conducted by Jackson et al (2003) and Reilly et al (2004) objectively measured physical activity in representative samples of young Scottish children aged 3-4 years and 3-5 year olds. Both studies reported low levels of engagement in MVPA, and high levels of engagement in sedentary behaviour similar to the levels reported in the present study (Jackson *et al.*, 2003; Reilly *et al.*, 2004).

To date there has been a paucity of research which compares physical activity objectively in rural and urban communities. This study has been one of the first to use objective methods to test the hypothesis that rural children are more active than urban children (LeMura *et al.*, 2000; Reilly *et al.*, 2003). The present exploratory study hypothesised that engagement in sedentary behaviour might be lower, and engagement in activity higher, in children from families living in a more rural environment. The results of the present study suggest that no such differences exist in young children, or if any differences do exist they must be very small. Time spent in light intensity physical activity and MVPA was very low and similar in both groups. Time spent in MVPA of around 3% corresponds to < 30 minutes per day, less than 60 minutes of MVPA recommended for children (Cavill *et al.*, 2001). In a recent review or correlates of physical activity Sallis et al (2000) argued that inconsistent evidence exists regarding environment and its association with physical activity, and suggested that it should be subjected to more detailed study.

Few studies have reported on objectively measured physical activity, and even fewer have reported on objectively measured sedentary behaviour. Published studies have used a variety of methods in a range of settings with different population samples and so have only been discussed briefly here. No directly comparable published studies were found. Savage and Scott (1998) reported on 822 US middle school adolescents (M = 229, F = 593), in three Indiana middle schools and found similar low levels of activity regardless of environment in children to the present study. These findings were in much older children (mean age = 13.9) who self-reported their participation in out-of-school physical activities over a 5 day period. The levels of reported activity reflected national US survey findings, indicating that many adolescents may not be involved in the recommended levels of activity and that exercise behaviours of rural adolescents were similar to those in urban areas.

Hakeem et al (2002) compared the physical activity level and total energy expenditure of 10-12 year old school children living at different levels of urbanization in Pakistan. Three groups of children were recruited from Punjab, Pakistan: rural, middle-income urban and high income urban, and another three groups of children were recruited from Slough, UK: British Pakistani, British Indian, and British Caucasian. Hakeem et al (2002) showed conflicting results to the present study for girls. Their results reported that girls (of Pakistani origin) physical activity level decreased significantly with the urbanisation rank. Hakeem et al (2002) concluded that physical activity levels of formally educated rural children, who have access to television have similar physical activity levels to their urban counterparts. Hakeem et al (2002) concluded that inactivity of urban girls needs particular attention.

Loucaides et al (2004) investigated differences in physical activity levels between urban and rural Greek-Cypriot children aged 11-12 years (n = 256). Physical activity was assessed using pedometers for 4 weekdays during the summer and 4 weekdays during the winter. Results showed that rural children were significantly more active during the summer than urban children ($p>0.001$), whereas urban children were significantly more active during the winter than rural children ($p>0.001$). Loucaides et al (2004) study suggested that the greater the time spent outdoors, the higher the physical activity levels of children are likely to be.

It is generally believed that boys are more active than girls (Thompson *et al.* 2003). Results from numerous studies (Riddoch *et al.*, 1991; Trost *et al.*, 1996; Hovell, *et al.*, 1999; Sallis *et al.*, 1999; Hussey *et al.*, 2001; Finn *et al.*, 2001; Metcalf *et al.*, 2002; O'Sullivan, 2002; Jackson *et al.*, 2003; Mallam *et al.*, 2003; Trost *et al.*, 2003; Montgomery *et al.* 2004; Reilly *et al.*, 2004) confirm this. In a study of 1540 boys and 1671 girls (age 11-18 years) in Northern Ireland, boys spent significantly more time physically active then girls at all ages (Riddoch *et al.*, 1999). However, the present study found that only rural Irish boys spent more time physically active that rural Irish girls at all physical activity intensities (Tables 6.5 and 6.6 in Appendix).

Limitations in the present study are similar to those reported in chapter 5. The accelerometer (i.e. MTI/CSA) used in this study is uniaxial (is designed to measure activity predominantly in the vertical plane), and while in theory measurement in two or three planes of movement might provide greater accuracy, empirical studies that have compared uniaxial vs. bi or triaxial accelerometry, do not bear this out (Welk *et al.*, 1995; Puyau *et al.*, 2002; Kelly *et al.*, 2003), and it is possible that there is a substantial vertical component to most young children's movements. As previously discussed in chapter 1 physical activity data were collected in 15-second epochs as recommended by Nilsson et al (2002) and Puyau et al (2002). However, to date there are no cut-offs to apply to the data the 15 second epochs in order to interpret accelerometer output, therefore data were summed in order to give 1-minute measurement intervals. In theory, as children's activity patterns are believed to be characterised by spontaneous and frequent bouts of brief exercise with random transitions to high and low intensities (Berman *et al.*, 1998), the use of 1-minute epochs might obscure vigorous intensity physical activity.

However, in practice it appears that the main consequence of this error is a small misclassification of some vigorous intensity physical activity as moderate intensity physical activity (Nilsson *et al.,* 2002). Further discussion of the limitations/strengths of accelerometers can be found in chapter 1. As previously mentioned in chapters 1 and 6 the most commonly used method is based on the Registrar General classification of occupations (Office of Populations Censuses and Surveys: OPCS 1990) and as previously mentioned has limitations, particularly at a time when unemployment is high, which lead to a high proportion of "unclassified" families.

Failure to observe differences in the physical activity between the rural Irish and the urban Scottish children could relate to lack of power, but the power calculation suggested that analysis of twenty pairs of subjects would be significant to detect very small differences of 100cpm in physical activity. No differences consistent with the hypothesis that engagement in physical activity was lower in the Scottish urban children were found. As the data from Ireland were collected from children from the same county, it would be worth repeating the study in a different part of Ireland or possibly a different country (possibly rural Africa, Asia) to see if the same results are observed.

The main strengths of the present study were the use of accelerometers to objectively measure physical activity and sedentary behaviour in young children. A further strength of the study was the use of broadly representative and homogenous sample. Most other studies have recruited a wider age range of samples and have not recruited broadly representative samples. In many previous cases the subjects may have been highly selected (Goran *et al.,* 1998).

6.6. Conclusion

In conclusion, the present study found low levels of engagement in moderate-vigorous physical activity, and high engagement in sedentary behaviour in modern Irish rural and Scottish 5 year olds. The very low levels of engagement in moderate-vigorous physical activity in these young children should give cause for public health concern. It would appear from the present study that children in a rural environment are not more active and that a rural environment may not protect young Irish children from high levels of sedentary behaviour. The present study should be replicated in other samples and settings. As physical activity levels of Irish and Scottish girls were consistently lower in all intensities of activity, further interventions focusing on girls may be advisable, but levels of physical activity were apparently low in both sexes. Furthermore, concerns for children's personal safety have been shown to impact strongly on recreational activity patterns (Sallis *et al.*, 1997a). Safety concerns may effect change in habitual activity patterns such as travel to school. It is interesting to note that while 51% of children interviewed in the O Sullivan study (2002) were transported to school by car, whereas 40 out of the 41 children measured in the present study travelled to school by car. The primary school may play an important role in children's socialisation into activity, both within and outside the formal school curriculum. Voluntary commitment by teachers to after-school sports is characteristic of many Irish primary schools. More research is needed to investigate factors affecting physical activity in rural Irish areas.

Chapter 7: Tracking Of Physical Activity And Sedentary Behaviour In Young Children In Glasgow

7.1. General Introduction

Many behaviours observed during adulthood are associated with risk of chronic disease morbidity and mortality (Kujala *et al.,* 1998; Josefson, 2001). Among these factors are cigarette smoking (Taoil and Wynder, 1991), consumption of high fat diets (Bray and Popkin, 1998) and sedentary behaviour/low physical activity (Raitakari *et al.,* 1994). Numerous public health initiatives have been directed towards reducing the prevalence of these behaviours among adults (McGinnis, 1992). It is now known that adult health behaviour change programmes are expensive and typically show high rates of recidivism (King, 1991). Therefore, intervention programmes aimed at the prevention of chronic diseases may be usefully focused on young children (Epstein *et al.,* 2000; Reilly *et al.,* 2004).

The maintenance of relative rank within an age-sex group so that a measurement over time tends to follow a pattern where initial measurements predict later levels in the same individual is termed "tracking" (Malina, 1996). It is widely assumed that children and adolescents who adopt high-risk behaviours (e.g. smoking) tend to maintain those behaviours throughout childhood and into adulthood (Pate *et al.,* 1996). Previous studies have demonstrated that blood pressure (Lane and Gill, 2004) and body composition (Fuentes *et al.,* 2003; Kvaavik *et al.,* 2003) tend to track during childhood. Each of these factors is likely to be affected by physical activity behaviour. Evidence exists suggesting this is the case for smoking (Taoil and Wynder, 1991) and dietary behaviour but less is known about physical activity and sedentary behaviour.

Little is known about physical activity and sedentary behaviour tracking in young children (Janz *et al.,* 2000). If low levels of physical activity and high levels of sedentary behaviour remain stable over a long period of time, one could argue for targeting at risk groups for interventions (De Bourdeaudhuij *et al.,* 2002).

Tracking is usually assessed by Pearson or Spearman Rank correlations across age groups (Maia *et al.,* 2001). If the values of the correlations reach a cut-off point of 0.50, it is usually assumed that the trait in question is a stable characteristic (Bloom, 1964) i.e. that it tracks (Pate *et al.,* 1996b; Jackson *et al.,* 2003; McMurray *et al.,* 2003). To date, a relatively small number of studies have examined the tendency of physical activity behaviour to track during childhood to adolescence and adulthood. These studies vary considerably with respect to length of follow-up, the population studied, the methods of assessing of physical activity, and the analytical method used to assess tracking (Pate *et al.,* 1999). Yet despite these variations the evidence suggests that over a relatively short interval (3-5 years), physical activity behaviour to some extent tracks over time (Sallis *et al.,* 1995). Data from several longitudinal studies indicate that youth at the extremes of the physical activity distribution (i.e. those lowest and those highest levels of physical activity) tend to retain their ranking with respect to physical activity over time (Raitakari *et al.,* 1995). While there is some evidence on the tracking of physical activity, there is a paucity of data on the tracking of *sedentary behaviour,* which may possibly track to a greater extent than physical activity (Janz *et al.,* 2000).

As tracking studies need longitudinal observations of the same individual over at least two points in time (Malina, 1996), much time and effort is needed and accordingly few studies are available. Research on tracking of physical activity and sedentary behaviour in young children is especially important in light of the recent reports by Montgomery et al (2004) and Reilly et al (2004), who reported very low levels of physical activity and total energy expenditure in young Glaswegian children.

In a review article on the tracking of physical activity, Malina (1996) reported low to moderate tracking of participation in physical activity and sports from childhood into adulthood. Despite this extensive review, the age span of the participants in the ranking studies were diverse with ages ranging from Raitakari et al study of tracking of physical activity in 3 year olds (Raitakari *et al.,* 1995) to Kuh and Cooper's physical activity tracking study in 23 year olds (Kuh and Cooper, 1992).

An early study by Pate et al (1996b) investigated whether physical activity tracks during early childhood in 47 US children (males = 22, females = 25) aged 3-4 years over a three-year period. Heart rate was measured for a minimum of two days and a maximum of 4 days per year. Physical activity was quantified as the percentage of observed minutes (between 3 p.m. and 6 p.m. only) during which heart rate was 50% or more over resting heart rate. Spearman Rank correlations ranged from 0.50 - 0.66 suggesting that physical activity behaviour during the afternoon tracked during early childhood.

Janz et al (2000) investigated tracking of physical activity and sedentary behaviour in a relatively large sample of US children (n = 126, mean age for boys = 10.8 years; mean age for girls 10.3 years) over a five-year period. Physical activity was assessed using self-reports and tracking of sedentary behaviour was assessed using television viewing/video game recall. Results showed that sedentary behaviour tracked better in boys than girls (r = 0.48-0.56 over five years), whereas vigorous activities tracked better in girls than boys (r = 0.43-0.65).

Similar results were found in a recent study by McMurray et al (2003). They investigated tracking of physical activity in a large sample of 1064 US children (males = 535, females = 529) age ranging from 8-16 years. Data on physical activity were collected using an unpublished questionnaire. Results from this study demonstrated a moderate degree of tracking of physical activity in children with Spearman Rank correlations ranging from 0.18-0.58.

McMurray et al (2003) concluded that although there is evidence only a moderate degree of tracking in children change in relative position is possible if physical activity interventions are introduced.

Methodological innovations have now made it possible to approach the topic of tracking of physical activity and sedentary behaviour more objectively and accurately. Previous studies have relied on heart rate monitoring (Pate *et al.,* 1996b), questionnaires (Telama *et al.,* 1996; Janz *et* al., 2000; De Bourdeaudhuij *et al.,* 2002), and surveys (McMurray *et al.,* 2003) to measure tracking, and as previously mentioned in chapter 1, these methods are fraught with difficulties.

7.2. Aims Of The Present Study

The primary aim of the present study was to examine the tracking characteristics of physical activity and sedentary behaviour in a relatively large and homogeneous sample of young Scottish children over a two-year period. A secondary aim was to investigate whether physical activity and sedentary behaviour tracked differently between the sexes.

7.3. Methods

7.3.1. Subjects

The subjects for this longitudinal study were 42 healthy children, who at the beginning of the study were 3.8 (SD 0.5) years of age. These children were a subgroup of the participants of a much larger mixed longitudinal study "SPARKLE" study (funded by the charitable organisation SPARKS i.e. Sport Aiding Medical Research for Kids) which investigated the levels of physical activity and total energy expenditure in a representative sample of Scottish pre-school children using accelerometers and doubly labelled water (Jackson *et al.,* 2003; Montgomery *et al.,* 2004; Reilly *et al.,* 2004).

In the SPARKLE study at baseline, 107 children and families consented to the study, at 12 months follow-up, 84 children and families participated and at 24 months follow-up 112 children and families participated. Evidence of tracking of physical activity was found in the SPARKLE study at 12 months follow-up (Jackson *et al.*, 2003). As previously mentioned in chapter 2 section 2.6.2, in the early stages of the "SPARKLE" study it was decided that satisfactory adherence to the physical activity measurement protocol at baseline (at 3 years of age) and 12 months follow-up (at 4.9 years of age SD 0.4), would be attained if a minimum of 6 hours per day (approximately 60% of the waking hours for a child of this age, Iglowstein *et al.*, 2003) for a minimum of 3 days (to include 1 weekend day) was recorded. At 24 months follow-up (5.8 years of age, SD 0.4) due to increased numbers of accelerometers and staff, it was decided that satisfactory adherence to the physical activity measurement protocol would be attained if a minimum of 6 hours per day (approximately 60% of the waking hours for a child of this age, Iglowstein *et al.*, 2003) for a minimum of 5 days (to include 1 weekend day) were recorded. The 42 children, upon whom the analyses presented in this study, were based adhered to the previously agreed protocol for collection of physical activity/sedentary behaviour data, and who provided the minimum accelerometer data required at baseline and 12 months and 24 months follow-up. All 1st year follow-up measurements were made 12 months ± 2months from baseline measurements. All 2nd year follow-up measurements were made 24 months ± 2months from baseline measurements.

7.3.2 Anthropometric Measurements

In each child, height was measured (to 0.1cm) using the Leicester Height measure and weight (to 1kg) in light indoor clothing using the SECA Scale for descriptive purposes only. From these measurements BMI was calculated and expressed relative to the UK reference data (Cole *et al.*, 1995) as a standard deviation score (SDS) using the software provided by the Child Growth Foundation, London.

7.3.3. Measurement Of Physical Activity And Sedentary Behaviour

Physical activity and sedentary behaviour were objectively measured using the MTI/CSA Accelerometer WAM-7164 (MTI, Shalimar, Florida) at baseline, 12 months and 24 months follow-up as previously described.

7.3.4. Statistical Analysis

Using the statistical package Minitab 13.32, all data were checked for normality prior to statistical analysis using descriptive statistics, histograms with normal distribution curves and using Anderson-Darling (AD) normality tests. Means and standard deviations (±SD) (or medians and range) were computed for anthropometric variables and physical activity and sedentary behaviour for each year of testing. A 2 sample t-test was calculated to test for significant differences between 42 subjects and the SPARKLE subjects. The SES distribution of the study sample was compared with that of the city of Glasgow using a chi-squared test. In keeping with recent research in this area, tracking of physical activity and sedentary behaviour was analysed in three ways (Pate *et al.,* 1996b; Pate *et al.,* 1999; Janz *et al.,* 2000; Jackson *et a.,* 2003; McMurray *et al.,* 2003). Firstly, year-to-year Spearman Rank correlations were calculated to examine tracking of physical activity and sedentary behaviour, according to Malina et al (1996). Secondly, percentage agreement, (as described by Bland and Altman, 2000) and thirdly KAPPA statistics (as described by Bland and Altman, 2000) between baseline and 12 month follow-up and baseline and 24 months follow-up were calculated to determine the likelihood that a particular child would be classified in the same group from year to year (Munoz, *et al.,* 1997). A KAPPA value of <0.20 represented a poor strength of agreement, 0.21 to 0.40 a fair strength of agreement, 0.41 to 0.60 a moderate strength of agreement, 0.61 to 0.80 a good strength of agreement, and 0.81 to 1.00 a very good strength of agreement (Bland and Altman, 2000).

7.4. Results

7.4.1. Characteristics Of Subjects

Satisfactory adherence to the simultaneous measurement protocols for both physical activity and sedentary behaviour was achieved for 42 children at each time point. The median accelerometry measurement period was 31.2 waking hours (range 18.1-39.1) at baseline and 79.2 waking hours (range 57.9-119.2 hours) at 24 months follow-up (Table 7.2). Subject characteristics are shown in table 7.1. Participants were representative of Glasgow in terms of socio-economic status (chi-squared test, $p = 0.00024$). There were no significant differences in antropometric or physical activity/sedentary behaviour measurements between the present studies participants and the SPARKLE study participants from which the sub sample was drawn ($p>0.05$; Table 7.2).

7.4.2. Tracking Of *Total Physical Activity* In Young Children From Baseline To 12 Months Follow-Up

Total physical activity was expressed as accelerometry count per minute (cpm), averaged over the entire recording period. Means and standard deviations and medians and ranges are presented in table 7.3. Spearman Rank correlations, and measures of agreement (Percentage agreement and KAPPA statistics) for baseline and 12 months follow-up are presented in table 8.4. Within the entire sample, Spearman Rank correlations for total physical activity were not statistically significant ($p>0.05$). Percentage agreement statistics for total physical activity from baseline to 12 months follow-up was 24%, while KAPPA statistics for the corresponding time were poor at –0.013 (Bland and Altman, 2000). In girls, Spearman Rank correlations for total physical activity approached significance ($p = 0.08$) but in boys correlations were not statistically significant ($p >0.05$). Percentage agreement statistics for total physical activity was similar in boys and girls (24% vs. 26% respectively), while KAPPA statistics for the boys and girls was poor (-0.03 vs. 0.01 respectively; Bland and Altman, 2000).

Table 7.1. Description Of Subjects By Group And Gender, Baseline, 12 months and 24 months Follow-up (Mean ± SD)

	Baseline	**12 Months Follow-Up**	**24 Months Follow-Up**
Age (yrs)			
Total Group (n=42)	3.8 ± 0.5	4.9 ± 0.4	5.8 ± 0.4
Boys (n= 21)	3.8 ± 0.4	4.8 ± 0.5	5.8 ± 0.3
Girls (n= 21)	3.7 ± 0.5	4.7 ± 0.4	5.8 ± 0.5
Height (m)			
Total Group (n=42)	1.00 ± 0.05	1.08 ± 0.05	1.15 ± 0.07
Boys (n= 21)	1.03 ± 0.05	1.10 ± 0.05	1.15 ± 0.08
Girls (n= 21)	0.99 ± 0.04	1.07 ± 0.04	1.14 ± 0.06
Weight (kg)			
Total Group (n=42)	16.4 ± 2.6	18.9 ± 3.5	20.7 ± 0.6
Boys (n= 21)	17.4 ± 2.5	18.7 ± 2.9	21.3 ± 4.1
Girls (n= 21)	15.3 ± 2.9	19.25 ± 4.0	20.1 ± 3.4
BMI (kg·m^2)			
Total Group (n=42)	15.9 ± 1.6	17.5 ± 3.1	17.7 ± 3.1
Boys (n= 21)	16.4 ± 1.6	17.0 ± 2.7	17.6 ± 2.8
Girls (n= 21)	15.6 ± 1.5	18.0 ± 3.6	17.8 ± 3.4
BMI SDS			
Total Group (n=42)	0.0 ± 1.3	0.9 ± 1.9	1.0 ± 1.7
Boys (n= 21)	0.3 ± 1.3	0.7 ± 1.8	1.0 ± 1.7
Girls (n= 21)	-0.2 ± 1.2	1.1 ± 2.0	1.0 ± 1.7

7.4.3. Tracking Of *Total Physical Activity* In Young Children From Baseline To 24 Months Follow-Up

Table 7.3 and Table 7.5 show means and standard deviations and medians and ranges, Spearman Rank correlations, and measures of agreement (Percentage agreement and KAPPA statistics) for baseline and 24 months of follow-up. Within the entire sample at 2nd year follow-up, Spearman Rank correlations for total physical activity showed statistically significant correlations ($p<0.05$). Percentage agreement statistic for total physical activity status from baseline to 24 months follow-up was 38%, while KAPPA statistic was poor at 0.17 (Bland and Altman, 2000). Analysis by gender (presented in Table 7.5) showed Spearman Rank coefficients in boys were not significant ($p > 0.05$); conversely Spearman Rank correlations in girls were not statistically significant ($p = 0.08$). Spearman Rank correlations and measures of agreement were similar in girls (% agreement statistic 38%, Kappa was poor at 0.17; Bland and Altman, 2000) and boys (% agreement statistic 38%, KAPPA was poor at 0.16; Bland and Altman, 2000).

7.4.4. Tracking Of *Moderate To Vigorous Physical Activity* In Young Children From Baseline To 12 Months Follow-Up

Means and standard deviations and medians and ranges are presented in table 7.3. Spearman Rank correlations and measures of agreement (Percentage agreement and KAPPA statistic) for baseline and 12 months follow-up are presented in table 8.4. Within the entire sample at 12 months follow-up, Spearman Rank correlations for MVPA were not statistically significant ($p>0.05$). Percentage agreement statistic for MVPA for the entire sample from baseline to 12 months year follow-up was 38%, and KAPPA statistic for the corresponding time was poor at 0.17 (Bland and Altman, 2000). The Spearman Rank correlation for MVPA was not significant in boys ($p > 0.05$) but was significant in girls ($p = 0.04$). Measures of agreement were slightly stronger in girls (% agreement statistics 33%, KAPPA was poor at 0.09; Bland and Altman, 2000) than boys (% agreement statistic 14%, KAPPA was poor at -0.16; Bland and Altman, 2000).

7.4.5. Tracking Of *Moderate To Vigorous Physical Activity* In Young Children From Baseline To 24 Months Follow-Up

Summary statistics are presented in Table 7.3. Spearman Rank correlations and measures of agreement (Percentage agreement and KAPPA statistic) for baseline and 24 months follow-up are presented in Table 8.5. Within the entire sample, Spearman Rank correlations for MVPA were significant ($p<0.05$). Percentage agreement statistic for MVPA from baseline to 24 months follow-up was 26%, and KAPPA statistic for the corresponding time was poor at 0.013 (Bland and Altman, 2000). The Spearman Rank correlations for MVPA were significant in boys ($p <0.05$) but not in girls ($p >0.05$). Measures of agreement were slightly stronger in boys (% agreement statistics 38%, KAPPA was poor at 0.16; Bland and Altman, 2000) than girls (% agreement statistic 33%, KAPPA was poor at 0.05; Bland and Altman, 2000).

7.4.6. Tracking Of *Sedentary Behaviour* In Young Children From Baseline To 12 Months Follow-Up

Means and standard deviations, correlation coefficients and measures of agreement (percentage agreement and KAPPA statistics) for physical activity are presented in Tables 7.3 and 7.4. Within the group, Spearman Rank correlations for sedentary behaviour were not statistically significant ($p >0.05$). Percentage agreement statistic for MVPA from baseline to 12 months follow-up was 26%, and KAPPA statistic for the corresponding time was poor at 0.17 (Bland and Altman, 2000). The Spearman Rank correlation for MVPA were not significant for boys ($p >0.05$) and girls ($p >0.05$). Measures of agreement were slightly stronger in girls (% agreement statistic 57%, KAPPA was fair at 0.39; Bland and Altman, 2000) than boys (% agreement statistic 44%, KAPPA was poor at -0.01; Bland and Altman, 2000).

7.4.7. Tracking Of *Sedentary Behaviour* In Young Children From Baseline To 24 Months Follow-Up

Tables 7.3 and 7.4 show means and standard deviations, correlation coefficients and measures of agreement (percentage agreement and KAPPA statistics) for sedentary behaviour. Within the group, Spearman Rank correlations for sedentary behaviour were statistically significant ($p < 0.05$). Percentage agreement statistic for MVPA from baseline to 24 months follow-up was 41%, and KAPPA statistic for the corresponding time was fair at 0.21 (Bland and Altman, 2000). The Spearman Rank correlation for MVPA was not significant for boys ($p > 0.05$) but was significant in girls ($p < 0.05$). Measures of agreement were slightly weaker in girls (% agreement statistics 20%, KAPPA was poor at 0.05; Bland and Altman, 2000) than boys (% agreement statistic 26%, KAPPA was poor at 0.01; Bland and Altman, 2000).

Table 7.2. Comparison Of Tracking Study Participants (n = 42) With Original SPARKLE Participants At Baseline (n = 107)

Variable	P-Value[5]	95% Confidence Interval
Age (yr)	0.468	(-0.2, 0.1)
Height (m)	0.914	(-0.02, 0.02)
Weight (kg)	0.620	(-0.8, 1.2)
BMI ($kg{\cdot}m^2$)	0.690	(-0.5, 0.7)
BMI SDS[1]	0.785	(-0.4, 0.5)
Total Hours Monitored (hrs)	0.066	(-0.1, 1.5)
Mean Total Physical Activity (cpm[2])	0.144	(-109.2, 16.2)
% Time Spent in MVPA[3]	0.210	(-1.3, 0.3)
% Time Spent in Sedentary Behaviour[4]	0.083	(-0.3, 4.1)

[1]SDS – standard deviation score relative to UK 1990 reference data, [2]cpm – counts per minute, [3]%MVPA – percent time spent in moderate and vigorous physical activity, [4]percentage of time spent in sedentary behaviour, [5]P value – obtained using a 2 sample T -tests for difference, * indicates significant difference between tracking study participants and SPARKLE participants

Table 7.3. Description Of Physical Activity Variables By Group And Gender, Baseline, 12 months and 24 months Follow-up (Mean ± SD, Median, range)

	Baseline	12 Months Follow-Up	24 Months Follow-Up
Total Activity (cpm)			
Total Group (n = 42)	669 ± 163	831 ± 233	818 ± 200
Boys (n = 21)	696 ± 169	896 ± 251	884 ± 191
Girls (n = 21)	642 ± 156	767 ± 198	753 ± 192
Total Hours Monitored (hrs)			
Total Group (n = 42)	31.2 (18.1, 39.1)	30.5 (14.9, 35.1)	79.2 (57.9, 119.2)
Boys (n = 21)	30.3 (21.7, 36.5)	28.8 (14.9, 35.1)	76.9 (57.9, 85.8)
Girls (n = 21)	31.9 (18.1, 39.1)	30.6 (23.5, 34.8)	82.1 (61.2, 119.2)
% Time in Sedentary Behaviour			
Total Group (n = 42)	80.5 (66.7, 90.2)	73.9 (55.0, 89.1)	74.1 (61.0, 90.3)
Boys (n = 21)	79.4 (69.0, 87.3)	71.7 (55.0, 87.9)	73.3 (61.0, 86.1)
Girls (n = 21)	81.6 (66.7, 90.2)	76.2 (59.1, 89.1)	77.6 (64.9, 90.3)
% Time in Light Intensity Activity			
Total Group (n = 42)	16.3 (9.0, 28.2)	22.2 (9.9, 34.8)	20.9 (9.2, 32.7)
Boys (n = 21)	18.7 (10.7, 27.0)	23.2 (11.6, 34.1)	22.5 (12.9, 32.7)
Girls (n = 21)	14.7 (9.0, 28.2)	20.5 (9.9, 34.8)	19.0 (9.2, 29.3)
% Time in Moderate-Vigorous Activity			
Total Group (n = 42)	2.2 (0.6, 7.9)	4.2 (0.2, 11.8)	4.1 (0.5, 14.0)
Boys (n = 21)	3.2 (1.0, 7.9)	4.8 (0.4, 11.8)	4.8 (1.0, 14.0)
Girls (n = 21)	2.1 (0.6, 5.6)	3.8 (0.2, 6.2)	3.8 (0.5, 7.3)

Table 7.4. Spearman Rank Order Correlations, Percentage Agreement And Kappa Statistics For Physical Activity And Sedentary Behaviour Measures, Baseline, and 12 months Follow-up

Physical Activity Measure	Spearman Rank Correlation		Percentage Agreement (%)	KAPPA
	R value	*P-value*		
Group Baseline and 12 Months Follow-Up (n = 42)				
Mean Total Physical Activity (cpm)	0.19	0.24	24	-0.01
% Sedentary Time	0.17	0.29	26	0.01
% Moderate-Vigorous Activity	0.22	0.15	38	0.17
Boys Baseline and 12 Months Follow-Up (n = 42)				
Mean Total Physical Activity (cpm)	-0.04	0.85	24	-0.03
% Sedentary Time	-0.15	0.51	24	-0.01
% Moderate-Vigorous Activity	0.07	0.75	14	-0.16
Girls Baseline and 12 Months Follow-Up (n = 42)				
Mean Total Physical Activity (cpm)	0.39	0.08	26	0.01
% Sedentary Time	0.35	0.13	57	0.39
% Moderate-Vigorous Activity	0.45	0.04*	33	0.09

Note: * Indicates significant difference

Table 7.5. Spearman Rank Correlations, Percentage Agreement And KAPPA Statistics For Physical Activity And Sedentary Behaviour Measures, Baseline, and 24 months Follow-up

Physical Activity Measure	Spearman Rank Correlation		Percentage Agreement (%)	KAPPA
	R value	*P-value*		
Group Baseline and 24 Months Follow-Up (n = 42)				
Mean Total Physical Activity (cpm)	0.35	0.02*	38	0.17
% Sedentary Time	0.35	0.02*	41	0.21
% Moderate-Vigorous Activity	0.37	0.02*	26	0.01
Boys Baseline and 24 Months Follow-Up (n = 42)				
Mean Total Physical Activity (cpm)	0.09	0.69	38	0.17
% Sedentary Time	-0.09	0.70	26	0.01
% Moderate-Vigorous Activity	0.44	0.04*	38	0.16
Girls Baseline and 24 Months Follow-Up (n = 42)				
Mean Total Physical Activity (cpm)	0.52	0.02*	38	0.16
% Sedentary Time	0.61	0.00*	42	0.05
% Moderate-Vigorous Activity	0.24	0.29	33	0.05

Note: * Indicates significant difference

7.5. Discussion

The present study is one of the few to examine the tracking of total physical activity, sedentary behaviour and MVPA in young children using objective methods. The results of the present study provide evidence that physical activity; MVPA and sedentary behaviour may track moderately over a two-year period.

In keeping with other studies in this area, Spearman Rank correlations were used to assess the extent of tracking within the sample of young Scottish children. The correlations between baseline and 12 months follow-up ranged from -0.04 to 0.45 and –0.09 to 0.61 for 24 months follow-up, indicating a relatively low to moderate level of tracking of total physical activity, sedentary behaviour, and MVPA. In absolute terms, these correlations are low to moderate when compared to Bloom (1964) who defined a stable characteristic as one that exhibits a correlation of greater than 0.50 for two measures obtained at least 1 year apart. Percentage agreement statistics for physical activity sedentary behaviour and MVPA for baseline to 12 months follow-up and baseline to 24 months follow-up ranged from 24% to 38% and 26% to 41%, while KAPPA statistics for the same time periods ranged from –0.013 to 0.17 and 0.013 to 0.21 again demonstrating low-moderate levels of tracking of total physical activity, MVPA and sedentary behaviour (Bland and Altman, 2000).

Pate et al (1996b) assessed physical activity using the quantum XL telemetry heart rate monitor for 2-4 days only between the hours of 3-6pm. Pate et al (1996b) showed stronger evidence of tracking in young children then the present study with significant Spearman rank correlations ranging from 0.57 – 0.66 ($p<0.001$). Percentage agreement ranged from 49-62% with strong KAPPA statistic of 0.81 (Bland and Altman, 2000) for the three-year study period. Pate et al (1996b) concluded that physical activity behaviour tends to track during early childhood. This study by Pate et al (1996b) was limited in a number of ways.

Firstly, physical activity data collection was limited to 3-6pm for only 2-4 days, which may not give an accurate account of the child's usual physical activity behaviour over the course of a day. Indeed, children may exhibit different patterns at different times in the day. Secondly all monitoring occurred on Monday through Thursday, excluding weekends. Again it may be argued that physical activity and sedentary behaviours could differ from weekdays and weekends although other studies argue no significant difference between weekend and weekday activity for modern young children in Scotland (Jackson *et al.,* 2003). Finally, tracking was measured using heart rates, which have serious limitations for use of measurement of physical activity especially in young children.

Sallis et al (1995) reported similar levels of tracking for total physical activity to the present study (r = 0.36) during playtime (recess) in 351 Mexican-American and Anglo-American 4 year old children. Physical activity was measured using direct observation (BEACHES; McKenzie *et al.,* 1991) for 10 days over a 2-year period, which consisted of only 2 days observations within one week. These measurements occurred every 6 months. The measurements occurred at home for a 60-minute period, in the evening and only 30 minutes during the school/preschool playtime period (recess). Sallis et al (1995) concluded that physical activity tracked better at home when 4 days of measurements were recorded (r = 0.36 vs. r = 0.15 for 1 single days observation), indicating low tracking of total physical activity. Unfortunately sedentary behaviour and MVPA were not measured during the study by Sallis et al (1995).

McKenzie et al (2003) assessed tracking of physical activity in 147 (n=76 boys, 71 girls) children of Euro and Mexican ethnic origin in the USA using the following objective measures: direct observation on 12 occasions in children aged 4-7 years (BEACHES method; McKenzie *et al.,* 1991); and two accelerometers (CALTRAC & MTI/CSA) on 4 occasions in older children aged 11-12 and 15-17 years; and the subjective method of interview using the physical activity recall method (PAR) in 177 children (n=88 boys and 89 girls). Interviews were conducted in the children's homes on 4 occasions (2 interviews 6 months apart at ages 11-12, and 2 interviews 6 months apart at ages 16-17 years).

McKenzie et al (2003) objectively measured accelerometer data found no significant correlations ($p>0.05$) for either gender indicating no evidence of tracking of physical activity. However, in their study using recall, significant correlations between self-report and physical activity were found in boys ($r = 0.37$) and in girls ($r = 0.31$). The discrepancies in the results (i.e. evidence tracking of physical activity when self reporting was used to measure physical activity and no evidence of tracking when accelerometry was used to assess tracking of physical activity) could be due to the known limitations of subjective methods for measuring physical activity and sedentary behaviours (Mckenzie *et al.,* 2003).

Benham-Deal (1999) examined tracking of MVPA during a four year mixed longitudinal study in 50 children aged 3-6 years (n=29 boys, 21 girls). Moderate-vigorous activity was assessed using heart rate monitoring (polar vantage X2 heart watch) for 12 hours on at least 2 days of each year. Subjects were divided into the following two-year periods: 3-4 years (n=18), 4-5 years (n=43), and 5-6 years (n=21). Tracking correlations for the 2-year study period were low ($r = 0.4$, $P <0.05$) and only significant in morning and evening periods for the second year of the study (4 to 5 years) demonstrating minimal tracking of MVPA in young children. Other studies have examined physical activity in slightly older children than those in the present study, using subjective measures such as previous day recall (Pate *et al.,* 1999), survey (compendium of physical activity) (McMurray *et al.,* 2003), and questionnaires (3 day sweat recall and TV/Video recall) (Janz *et al.,* 2000). These studies have generally found similar results to the present study i.e. low to moderate levels of tracking of total physical activity in young children. Though correlations are variable between studies, the results suggest low to moderate short term tracking of activity in transition from early to middle childhood.

This study had several strengths. First, compared to some previous tracking studies, accelerometry was used to measure both physical activity and sedentary behaviour. Second a relatively large, homogeneous, socio-economically representative sample of young Scottish children was studied. Most previous studies have not recruited representative samples, and in many cases study subjects may have been highly selected. A further strength of the present study was the use of multiple indices of tracking.

In addition to the traditional Spearman Rank correlations, percentage agreement and KAPPA statistics were calculated to examine tracking of physical activity and sedentary behaviour. Calculating percentage agreement assessed the extent to which subjects remained in their respective physical activity behaviours category from year to year, and finally KAPPA statistics were examined. Consequently, conclusions regarding the tendency of total physical activity, sedentary behaviour and MVPA track from baseline to 2nd year follow-up were based on several sources of complementary information.

It is important to note that the present study had several limitations. Firstly, this study was conducted with relatively short follow-up periods of 12 and 24 months. Therefore conclusions should be regarded with some caution. However, as physical activity and sedentary behaviour were measured using accelerometers, results may be viewed with more confidence than previous studies where subjective measures measured physical activity. Secondly, due to the nature of the study some of the children were measured during the autumn and winter months. It could therefore be argued that physical activity might be lower in winter months than spring and summer months, results may have been different if measurements were conducted during the summer months. However, a recent study conducted by Fisher et al (2005) using the MTI/CSA accelerometer in young Scottish children concluded that differences in physical activity levels between summer/autumn and spring/winter were negligible in young Scottish children.

Thirdly, it is possible that correlation co-efficients underestimate the true level of tracking within the group, given that only one 3-7 day measurement of total physical activity, sedentary behaviour and MVPA behaviour was carried out a year. A larger number of measurements may be expected to produce a more reliable index and a higher tracking co-efficient (Pate *et al.,* 1999). Finally, failure to observe stronger evidence of tracking of total physical activity and sedentary behaviour could relate to lack of power.

7.6. Conclusions

The results of the present study suggest that there is low to moderate tracking of physical activity, sedentary behaviour and MVPA in young children in Glasgow. The present studies finding of low to moderate tracking implies a good deal of movement from year to year. These data raise the possibility that interventions targeted at young children to promote and increase physical activity and more importantly decrease sedentary behaviour may change tracking trajectories. However, it should be noted that the sample in this tracking study was inactive at all three-time points of the study, and so the amount of movement from year to year was not that great. The findings of the present study may carry important implications for policy and practice in the fields of public health. Further research in this area is clearly warranted.

Chapter 8: General Discussion and Future Research

Children's physical activity, as well as their sedentary behaviour, has provided serious measurement challenges for researchers. However, methodological limitations have inhibited research in this area. An improved understanding of basic aspects of physical activity in early childhood is necessary in order to prevent obesity: to identify when, how, and in whom to target interventions. An expert panel for the Centers for Disease Control (CDC) recently suggested some research priorities in the field of paediatric physical activity and sedentary behaviour (Fulton *et al,* 2001). A number of topics suggest by the expert committee have been addressed in the studies reported in this thesis. The first recommendation suggest by the committee was to compare different types of motion sensors currently available for pre-school children. Therefore, the first two studies of this thesis are methodological investigations of accelerometers. The remaining studies set out to address some of the CDCs recommendations for studies on the determinants of physical activity and sedentary behaviour in young children, in particular socio-economic status and environment.

The first experimental chapter in this thesis set out to address the methodological problem of accelerometers, by comparing two popular accelerometers (MTI/CSA and Actiwatch accelerometers) against the criterion method of direct observation in young preschool children (chapter 3). To my knowledge this was the first study to directly compare the bi-axial accelerometer (Actiwatch) and the uni-axial accelerometer (MTI/CSA accelerometer) ability to accurately measure physical activity against a criterion method. Both accelerometers have been compared with other methods of physical activity measurement but never directly compared. The results of this study highlighted some major errors in the internal process of the Actiwatch accelerometer, thus highlighting that the uni-axial accelerometer may in fact measure physical activity and sedentary behaviour more accurately than bi-axial accelerometers.

Many researchers assume that the biaxial and triaxial accelerometers may measure total physical activity better due to their ability to record physical activity in more than one plane. However, Chapter 3 does not support this suggestion. This study has important implications or future research on physical activity behaviours of young children. This study highlights the importance, when choosing an accelerometer of knowing the acceleration magnitude and the frequency response. Each manufacturing company have chosen different accelerations and frequency response for their accelerometer, it is vital that one understands what these mean and therefore what movements they measure (i.e. little movements such as fidgeting or large movements such as running). There are also other important issues such as cost and size. Size becomes especially important when the subjects are young children. The debate however over the use of uniaxial versus bi-axial or triaxial accelerometers will continue. However this study will help future researchers have a more informed choice on which accelerometer better suits the need of their study.

The second methodological chapter of this thesis (chapter 4) set out to cross-validate a cut-off for sedentary behaviour, and concludes that accelerometry could be used much more widely now that validity is established for measurement of both activity and sedentary behaviour. Much of the research to date has used adult cut-off points, which are not applicable to children. The 1100cpm cut-off has been cross-validated in been a separate sample of pre-school children and due to it's high sensitivity and specificity may give researches greater reassurance in their measurement of sedentary behaviour. But the issue of valid age appropriate cut-offs to denote sedentary behaviour and physical activity remains unsolved and is still fraught with controversy (Janz, 1994; Puyau *et al.,* 2002; Reilly *et al.,* 2004; Ekeland *et al.,* 2004; Wilkin and Voss, 2004). Further research on validation of different age and ethnic specific cut-points may be necessary.

Although there is now extensive and compelling literature documenting the health benefits of regular physical activity in adults, and the relationship between activity and health in children are far from clear-cut. At present there is a discernible feeling that children are less physically active than in the past. In fact, the current perception of an increasingly sedentary way of life among young children is even more widespread than it is for adults. This in turn has prompted concerns about the impact of these declining levels of physical activity and the increasing levels of sedentary behaviour among young children. Most existing data have been obtained from older children using subjective techniques, or from studies before the obesity epidemic. Therefore, results obtained in this thesis provide valuable data in relation to physical activity and sedentary behaviour of pre-school children, specifically Scottish and Irish pre-school children.

The first biological study of this thesis, aimed to address the reasons for this social patterning in childhood obesity, which remain unclear (Chapter 5). Previous studies investigating the disparity in the obesity risk between families from higher and lower socio-economic status used subjective techniques to measure physical activity, these measurement techniques are susceptible to under and/or over reporting The results of this study found a low level of engagement in moderate-vigorous physical activity, and high engagement in sedentary behaviour was found in modern Scottish 5 year olds independent of SES. The very low levels of engagement in moderate-vigorous physical activity in these young children should give serious cause for public health concern. Differences between children from affluent or deprived families were not consistent with the hypothesis that differences in physical activity or sedentary behaviour underlie socio-economic variations in obesity risk. The results presented in this thesis contribute to the growing body of knowledge of the effect of SES on childhood obesity showing that objectively measured habitual physical activity of young children was not influenced by socio-economic status, and socio-economic differences in obesity risk are likely to be due to social patterning of dietary intake.

Due to recent research demonstrating very low levels of physical activity in preschool children (Jackson *et al.,* 2003; Montgomery *et* al., 2004) many researchers assume that rural children due to their environment are more physically active than their urban peers. To date there is paucity in research comparing objectively measured physical activity in rural and urban communities. However the result of chapter 6 of this thesis suggest otherwise. Low levels of engagement in moderate-vigorous physical activity, and high engagement in sedentary behaviour were found in modern Irish rural and Scottish 5 year olds (Chapter 6). All children regardless of milieu spent greater than 70% of their waking time engaging in sedentary behaviours, and only 3% of their time in MVPA. Differences between children from rural or urban families were not consistent with the hypothesis that children from rural backgrounds spend more of their time engaged in physical activity and less time in sedentary behaviour than urban children, reported in other studies. It would appear from the present study that rural life may not protect one from high levels of sedentary behaviour in early childhood, but further comparisons between urban and rural samples would be desirable. However this study is the first to objectively measure physical activity and sedentary behaviour in a more socio-economically representative sample of young children, and may provide researchers with a more solid and accurate representation of physical activity of modern urban and rural children. This study also highlights need for interventions specifically aimed at rural children.

One reoccurring finding of chapter 5 and 6 is that boys spend less time in sedentary behaviour and more time in light physical activity than girls. This finding is not unique to the studies in thesis or to this age group, although it is a pattern of physical activity believed to be primarily of adolescents. Research has shown that even as young as preschool age, boys tend to more physically activity and engagement in sedentary behaviour is lower than girls (Pelligrini *et al.,* 1998; Jackson *et al.,* 2003; Montgomery *et al.,* 2004 Reilly *et al.,* 2004; Kelly *et al.,* 2005). One partial explanation for the disparities in physical activity and sedentary behaviour levels between boys and girls seen in this thesis and a number of other studies may be due to differential maturation rates of boys and girls, where by virtue being further on the developmental trajectory for motor skills, girls may appear to be more active (Eaton and Yu, 1989).

A complementary explanation, following social learning theory, is that as children mature they also learn sex role expectations, where being physically active is something that only boys do (Pellegrini *et al.*, 1998).

In light of the previous two studies results and also the evidence suggesting tracking of health behaviours from childhood to adulthood the objective of chapter 7 was to take advantage of these methodological developments in accelerometers to examine the tracking characteristics of habitual physical activity, MVPA and sedentary behaviour in a relatively large and homogeneous sample of young Scottish children over a two-year period. Research using subjective techniques have reported moderate to high levels of tracking of physical activity in children older than those in this thesis (Pate *et al.*, 1996, Benham-Deal *et al.*, 1999; Pate *et al.*, 1999). The findings of chapter 7 suggest that there is low tracking in young children, therefore, this group at this stage of their young lives should be targeted with interventions to promote and increase physical activity and more importantly decrease sedentary behaviour. The findings of the present study may carry important implications for policy and practice in the fields of public health. Further research in this area is clearly warranted.

In conclusion results of different studies are often difficult to interpret and compare, owing to the diversity of methodological approaches used to assess physical activity and sedentary behaviour, differences in data analysis, and reporting and the adoption of varying definitions for what constitutes an appropriate level of activity, making a summary and comparison of findings difficult. Much of the data provides little more than a gross estimate that is based on some form of children's self report or questionnaire. A major strength of the studies investigated in this thesis is that unlike previous research objective methods i.e. the accelerometer has been used to quantify physical activity in representative samples of the populations being investigated. Furthermore, unlike much of the data seasonal variability in patterns of physical activity and sedentary behaviour was accounted for.

8.1: Future Research

Experts agree that there is a need to promote physically activity and reduce sedentary behaviour in young children, but what further studies are required??? There has been extensive research into the effects of different types and levels of physical activity in the adult population and indeed a massive research project has reported on the physical activity levels of young adolescent Europeans measured using accelerometry (Riddoch *et al.*, 2004), but no large-scale research studies using objective techniques such as accelerometers have been undertaken in young pre-school children.

There is also the need for the collection of data on the following areas:

- *The effects of physical activity on children's' short and long term life.*

The effects of physical activity on cognitive (e.g. fundamental movement skills), physiological (e.g. blood pressure), and mental health (self perception) in preschool children are virtually unknown.

- *The appropriate amount of physical activity need for health.*

Currently, there is no firm *scientific* underpinning to the current physical activity recommendations for promotion and maintenance of health during childhood. Due to past methodological constraints, current paediatric guidelines borrow from the evidence of health benefits in adults' studies (Livingstone *et al.*, 2003).

- *Factors which influence young children's participation in physical activity.*

Identify factors, which are associated with physical activity and sedentary behaviours may be important for further intervention studies, aimed at decreasing sedentary behaviours and promoting a physically active lifestyle in young children.

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APPENDIX A

Table 1.1 Characteristics of Physical Activity Assessment Techniques

	Group		Study		Subject				
Assessment method	Age	Size	Cost	Time	Time	Effort	Limitations	Validity	Reliability
Direct calorimetry	Infant –elderly	S	H	Hours-day	Hours-days	Movement	Cost, lab setting	H	H
Indirect calorimetry	Adolescent-elderly	M	M	Minutes-hours	Minutes-hours	Artificial activity	Lab setting	H	H
Doubly labelled water	Infant -elderly	S	H	2-3weeks	Minutes-day	Urine collection	Cost, only ADEE	H	H
PA index / job classification	Employed only	L	L	Days	Minutes	ID work activity	Only occupational PA	L	M
Surveys PA diary	Adolescent-elderly	L	M	One day	Throughout the day	Detail activity	Time	M	M
Recall questionnaire	Adolescent-elderly	L	L	1-7 days	Less than1 hr	Recall activity	Subject memory	M	M
HR monitoring	Infant-Elderly	M	H	Minutes-days	1hr +	Calibration test	Only at moderate levels	M	H
Pedometers	Child-Elderly	L	L	1-3days	Very low	Wear on belt	Only walking/running	M	M
Uniaxial accelerometers	Infant-elderly	M	H	1. -3days	Very low	Wear on belt	Uni dimensional	M	M
Triaxial accelerometers	Infant-Elderly	M	H	1-3days	Very low	Wear on belt	Cost, static activities	M	M

Note: S=Small, M = medium, L = large sample size, H = high

Height Measure

The Equipment

The Leicester height measure (Child Growth Foundation, London UK) is a portable stadiometer, which is collapsible and consists of a base plate, a head plate and some connecting rods marked with a measuring scale.

Procedure

The stadiometer is assembled and the head plate raised in order to allow sufficient room for the child to stand underneath it. The children are measured in light outdoor clothing. In addition to removing their shoes, the child being measured removes their socks as well. This is not because socks affect the measurement but rather to ensure that children do not lift their heels off the base plate. The child stands with their feet flat on the centre of the base plate, feet together and heels against the rod. The child's back is as straight as possible, against the rod, and their arms hang loosely by their sides. The face forwards (see Figure 1.4 in Appendix). The measuring arm is placed just above the child's head. The child's head is moved so that the Frankfort plane (see 1.5) is in a horizontal position. This position is as important if the measurements are to be accurate. To make sure that the Frankfort Plane is horizontal, the Frankfort plane card can be used to line up the bottom of the eye socket with the flap of skin on the ear. The Frankfort plane is horizontal when the card is parallel to the stadiometer arm (see Figure 2.5 in Appendix). The children is asked to breathe in and stand up straight and tall but not to move their heads or stand on their tiptoes. The height value is then read in metric units to the nearest completed millimetre

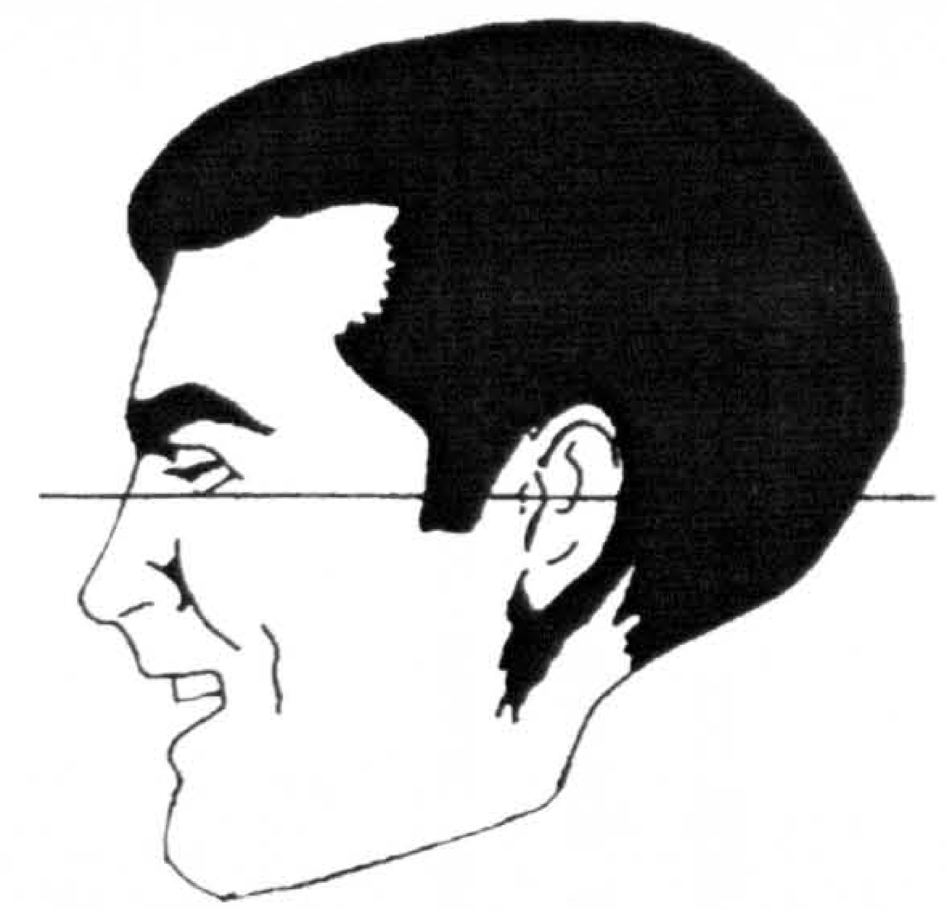
Additional point

If the respondent had a hairstyle, which stood well above the top of their head the respondent, was asked to change/undo it.

Figure1.4. Measuring height using the Leicester Height Measure

(Source: National Diet and Nutrition Survey: children aged 12 to 42 years 1992

Figure 1.5. Head in Frankfurt Plane



(Source: National Diet and Nutrition Survey: children aged 12 to 42 years 1992)

Weight Measurement

The Equipment

The SECA Alpha scales (SECA UK) are turned on by pressing the top of the scale (e.g. with your foot). There is no switch to turn the scales off, they turn off automatically. The reading is only in metric units.

Procedure

The scales are turned on by pressing firmly with your hand or foot on the top of the scales (the scales will turn themselves off after a short while). The readout displays 888.8 momentarily as a check for the operation wait until the scales reads 0.0 before attempting to weigh anyone. The child is again weighted in light outdoor clothes in his bare feet. The scales are turned on again and when the display reads 0.0 the child is asked to stand on the scales. The child stands with their feet together in the centre of the scales (Figure 1.6 in Appendix). Their arms hang loosely at their sides and their head faces forward. The child is asked to stand still and look forward until the weight in kilograms is registered. The posture is very important if they stand to one side, look down, or do not otherwise have their weight evenly spread, it can affect the reading. Weight is then recorded to the nearest 0.1kg.

Figure 1.6. Measuring weight using SECA Scales

Note: Source: National Diet and Nutrition Survey: children aged 12 to 42 years 1992

APPENDIX D

Childrens Physical Activity Form

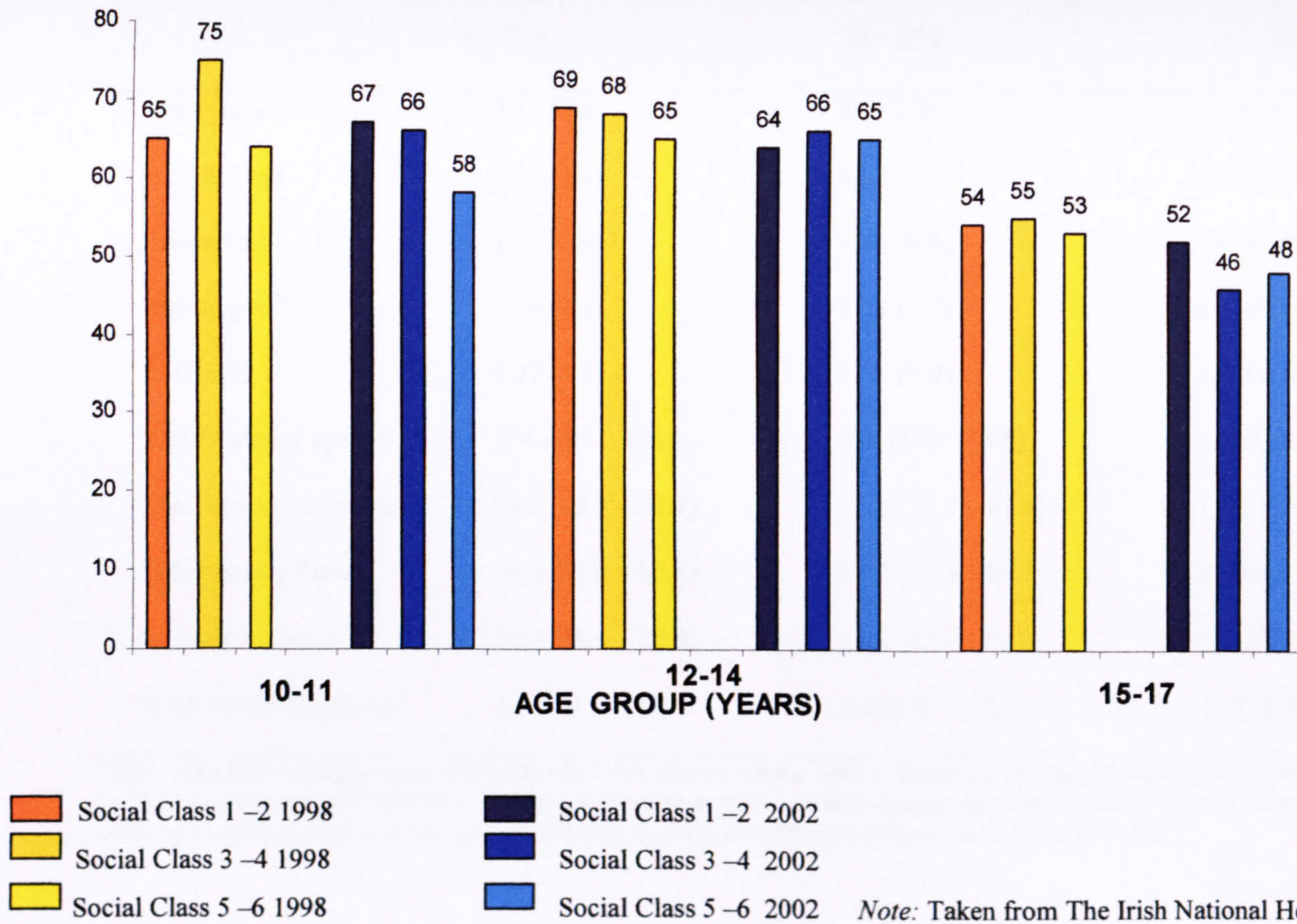
OBSERVATION SHEET

ME01

MIN	TIME	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	TOTAL	NOTES
1	1:02		✓	✓		150	
2	1:03		✓	✓		150	
3	[illegible]			✓		150	
4	5			✓		150	
5	6			✓		150	
6	7		✓	✓		150	
7	8		✓	✓		150	
8	9			✓		150	
9	10			✓		150	
10	11		✓	✓		150	
11	12			✓		150	
12	13			✓		150	
13	14	✓		✓		150	
14	15			✓	✓	210	
15	16				✓	240	
16	17		✓	✓		150	
17	18				✓	240	
18	19		✓		✓	150	
19	20		✓	✓		150	
20	21	✓				60	
21	22	✓				60	
22	23	✓				60	
23	24	✓		✓		120	
24	25			✓		150	
25	26		✓			1[illegible]0	
26	27			✓		150	
27	28		✓	✓		150	
28	29		✓	✓		150	
29	30			✓	✓	210	
30	31				✓	240	
31	32			✓	✓	210	
32	33			✓		150	
33	34			✓	✓	210	
34	35			✓	✓	210	
35	36			✓	✓	210	
36	37			✓		150	
37	38			✓		150	
38	39			✓		150	
39	40			✓		150	
40	41			✓		150	
41	42		✓	✓		150	
42	43		✓	✓		150	
43							
44							
45							6990

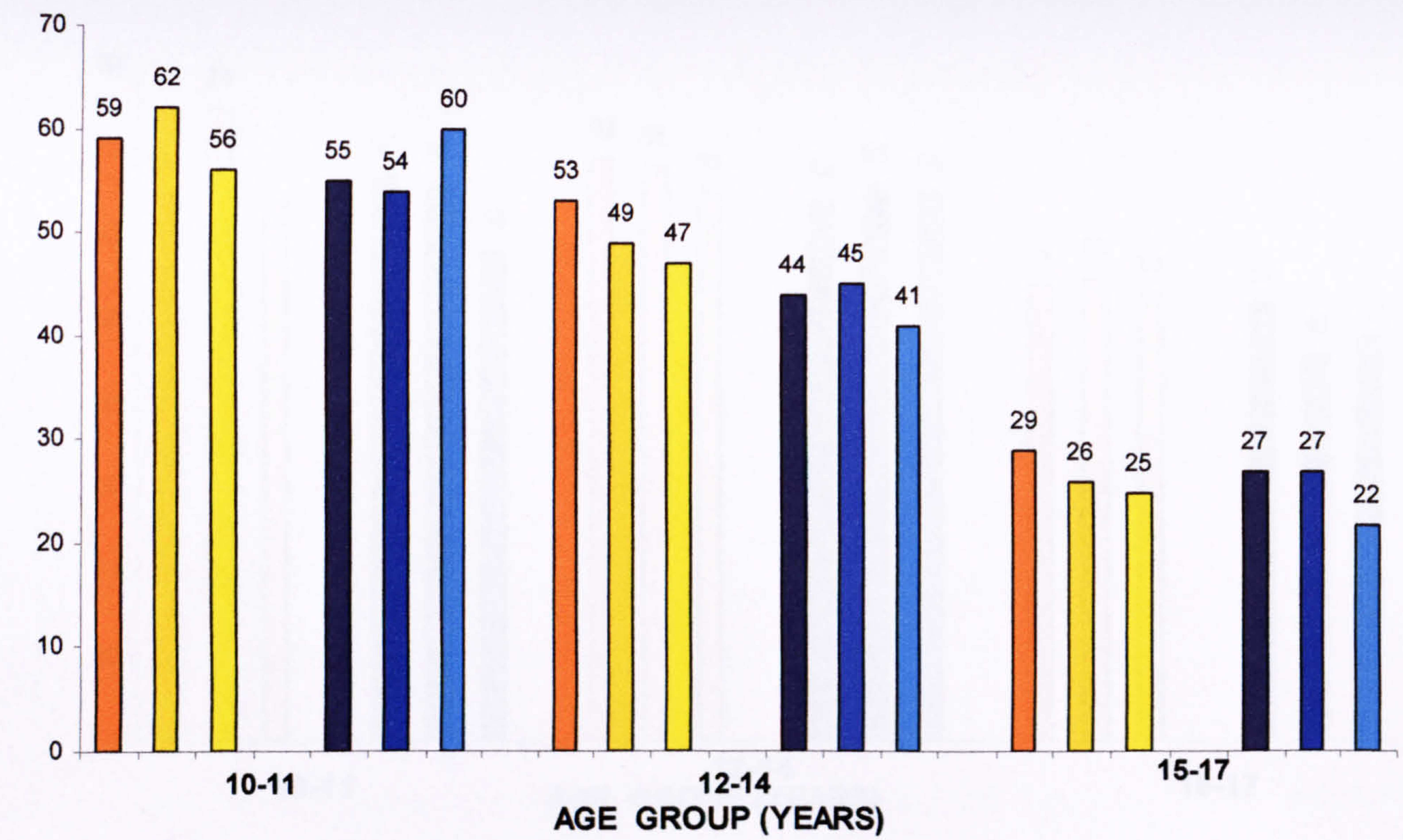
APPENDIX E

Figure 7.1a. Percentage Of Boys Who Report Participating In Vigorous Exercise Four Or More Times Per Week By Social Class



Note: Taken from The Irish National Health and Lifestyle Study (2002)

Figure 7.1b. Percentage Of Girls Who Report Participating In Vigorous Exercise Four Or More Times Per Week By Social Class



Note: Taken from The Irish National Health and Lifestyle Study (2002

Table 7.5. Rural Subjects by Gender (N = 41; Mean And Standard Deviation; Median And Range).

Variable	Rural Irish Boys (n= 21)	Rural Irish Girls (n= 21)	95% Confidence Interval	p value[6]
Age (years)	5.1 (1.0)	5.5 (0.3)	(-0.9, 0.1)	0.15
Weight (kg)	22.4 (3.6)	22.2 (2.9)	(-2.2, 1.8)	0.56
Height (m)	1.13 (0.04)	1.13 (0.05)	(-0.03, 0.02)	0.80
BMI (kg/m^2)	17.6 (2.1)	17.3 (1.7)	(-1.10,1.30)	0.96
BMI SDS[1]	1.27 (1.1)	1.01 (0.9)	(-0.38, 0.89)	0.42
Total Activity cpm[2] +	834 (705 – 925)	628 (542 – 791)	(79.0, 269.0)*	0.0015
Total Hours Monitored	74.9 (42.2 – 83.7)	77.1 (58.3 – 83.8)	(-12.13, 0.51)	0.070
% Sedentary Time[3]	74.4 (53.0 – 86.8)	81.9 (74.3 – 89.3)	(-10.4, -2.7) *	0.001
% Light Minutes[4]	20.3 (18.6 – 23.4)	15.8 (13.6, -19.2)	(1.8, 7.2) *	0.0031
% Moderate-Vigorous[5]	4.2 (2.4 – 5.9)	2.4 (1.4 - 3.3)	(0.3, 2.7)*	0.0176

[1]SDS – standard deviation score relative to UK 1990 reference data, [2]cpm – counts per minute, [3]percentage of time spent in sedentary behaviour, [4]percent of time spent in light intensity activity, [5]%MVPA – percent time spent in moderate and vigorous physical activity, [6]P value –obtained on performing Mann-Whitney tests for difference between rural boys and girls, * indicates significant difference between rural boys and girls.

Table 7.6. Urban Subjects by Gender (N = 41; Mean And Standard Deviation; Median And Range).

Variable	Urban Scottish Boys (n= 21)	Urban Scottish Girls (n= 21)	95% Confidence Interval	p value[6]
Age (years)	5.7 (0.5)	5.5 (0.4)	(-1.1, -0.05) *	0.034
Weight (kg)	20.9 (3.8)	20.9 (4.1)	(-1.09, 4.1)	0.24
Height (m)	1.15 (0.09)	1.14 (0.09)	(-0.07, 0.0)	0.46
BMI (kg/m^2)	16.0 (1.9)	16.4 (2.6)	(0.29, 2.8) *	0.019
BMI SDS[1]	0.4 (1.2)	0.3 (1.2)	(0.16, -1.7)	0.020
Total Activity cpm[2]	787 (477, 918)	722 (482, 1062)	(-84, 127)	0.4263
Total Hours Monitored	75.6 (46.8, 89.0)	74.4 (46.7, 91.2)	(-12.6, 4.1)	0.3682
% Sedentary Time[3]	77.0 (71.4, 86.9)	79.9 (66.8, 88.5)	(-4.3, 1.9)	0.3823
% Light Minutes[4]	18.5 (12.3, 24.5)	17.9 (10.0, 25.8)	(-1.3, 3.5)	0.4494
% Moderate-Vigorous[5]	3.5 (0.8, 6.0)	3.0 (1.0, 8.0)	(-1.2, 1.0)	0.8136

[1]SDS – standard deviation score relative to UK 1990 reference data, [2]cpm – counts per minute, [3]percentage of time spent in sedentary behaviour, [4]percent of time spent in light intensity activity, [5]%MVPA – percent time spent in moderate and vigorous physical activity, [6]P value –obtained on performing Mann-Whitney tests for difference between urban boys and girls, * indicates significant difference between urbanl boys and girls.

ACSM, Nashville, US, 2005

Tracking of Physical Activity and Sedentary Behavior in Young Scottish Children.

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It would be valuable if at risk groups with low physical activity could be identified early and offered targeted intervention. Unfortunately, little is known about the tracking either of total physical activity, moderate to vigorous activity (MVPA) or sedentary behavior in young children. **PURPOSE:** The aim of the present study was to examine the tracking characteristics of total physical activity (PA), moderate to vigorous activity (MVPA) and sedentary behavior in a relatively large and homogeneous sample of young Scottish children over a three-year period. **METHODS:** The tracking of total physical activity, MVPA and sedentary behavior was examined in Glasgow, Scotland, UK at baseline then 12 and 24 months later. Subjects were 21 boys and 21 girls (mean age boys 3.8 SD 0.4 and girls 3.7 SD 0.5). Total physical activity, MVPA and sedentary behavior were measured objectively for 7 consecutive days annually using the MTI/CSA accelerometer. Time spent in MVPA and sedentary behavior was established using published pediatric cut-offs. In keeping with recent research in this area, tracking of physical activity, MVPA and sedentary behavior were analyzed in three ways: Spearman Rank correlations, percentage agreements and finally KAPPA statistics. **RESULTS:** For total physical activity Spearman rank correlations ranged from 0.17-35; for MVPA Spearman and rank correlations ranged from 0.22-0.37; and for sedentary behavior Spearman rank correlations ranged from 0.17-0.35. Percentage agreement for total physical activity, MVPA and sedentary behavior ranged from 24%-38%, 26%-38% and 26%-41% respectively. KAPPA statistics for total physical activity, MVPA and sedentary behavior ranged from poor to fair. **CONCLUSION:** These results indicate low levels of tracking of total physical activity, MVPA and sedentary behavior in young Scottish children over a three-year period.

Medicine & Science in Sports & Exercise.2004 36(5) S2271.

Objective measurement of physical activity in pre-school children: comparison of two accelerometers against direct observation.

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Measurement of physical activity in young children must be objective, since self or parental reports are not valid. The advent of accelerometry has provided a practical and accurate means of objectively assessing engagement in habitual physical activity and inactivity (sedentary behaviour) suitable even in young children. However, there is a paucity of data on physical activity in young children, in part because accelerometry has become available only recently, and in part because of limited evidence on the validity of accelerometers in young children. Pre-school children, are thought to have movements which are highly transitory and more tortional. This might make the method of accelerometry important. **PURPOSE**: The aim of this study was to compare two accelerometers, the computer science and applications (CSA-7164) and Actiwatch, against direct observation of physical activity using the Children's Physical Activity Form (CPAF) (O'Hara *et al.*, 1985). **METHODS**: CSA-7164 and Actiwatch accelerometers simultaneously measured activity during 35-45 minute sessions of structured play in 78, 3-4 year olds. Rank order correlations between accelerometry and direct observation were used to assess the ability of the accelerometers to assess total activity. Within-child by minute correlations was also calculated between accelerometry output and direct observation. RESULTS: For assessment of total activity CSA output was significantly positively correlated with CPAF (r 0.72, $p<0.001$), but output from the Actiwatch was not (r 0.16, $p>0.05$). **CONCLUSION**: The present study suggests that for epidemiological assessment of total physical activity in young children the CSA-7164 provides greater accuracy than the Actiwatch.

Proc Nutr Soc, Dublin, 2004.

Objectively measured physical activity and inactivity in rural Irish and urban Scottish children: A comparison study.

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The recent obesity epidemic in children has led to an increased awareness of physical inactivity as a serious medical and public health concern. However, to date there is a paucity of data on objectively measured physical activity and inactivity in contemporary populations of children. We hypothesised that young Irish children from rural areas might be expected to be more physically active than children from urban areas. In the present study, we measured levels of activity and inactivity in a sample of contemporary rural Irish Children and compared them with children from Glasgow. We studied forty-one pairs (n=82) from a broadly socio-economically representative sample of children aged 4-6 years old (mean age 5.3, RANGE: 4.3-6.4YRS) from Co. Carlow, Ireland and Glasgow, Scotland. Total physical activity (mean accelerometer count/minute), inactivity (% of monitored time below 1100 counts/minute; and time spent in light activity, and moderate-vigorous physical activity (MVPA) were assessed over 7 consecutive days using the Actigraph accelerometer. Man-Whitney U test or Wilcoxon signed rank test where appropriate, were used to test the significance of any differences in anthropometric characteristics, engagement in physical activity or sedentary/inactive behaviour between the Irish rural subjects and the Scottish urban subjects (see Table). The significance level was set at 5%. We found no significant differences in any of the anthropometric measurements in the two settings. Irish and Scottish boys were significantly more active than the Irish and Scottish girls but there were no significant differences in total activity for each sex group in the two areas. Engagement in sedentary behaviour was high in both the Irish and Scottish children. We found no significant differences between the two sex groups for any aspect of physical activity or inactivity. This present study has been the first to measure physical activity and inactivity in Irish rural children objectively. It shows that levels of physical activity and engagement in inactivity are similar in children in rural Ireland and in urban Scotland. The amount of inactivity in both settings at this young age is a major concern.

Variable (Median (range))	Irish Children (N=41)	Scottish Children (n=41)	P
Total Activity (CPM)	726 (395, 1287)	762 (477, 1062)	0.61
% Sedentary Time (≤1100cpm)	77.6 (53.0, 89.3)	78.7 (66.8, 88.5)	0.83
% Light Activity (>1101-<3200 cpm)	18.8 (9.9, 39.9)	18.3 (10.0, 25.8)	0.83
% Moderate-Vigorous Activity (≥ 3200 cpm)	3.0 (0.7, 8.2)	2.8 (0.8, 8.5)	0.89

Table: Physical activity/inactivity characteristics. *P* values obtained by Wilcoxon signed rank test.

Proc Nutr Soc 2003 2A.

Differences in habitual physical activity and inactivity in young children from deprived versus wealthy families. By L.A. KELLY[1], J.J. REILLY[1], S. GRANT[2] and J.Y PATON[1], [1]*Division of Developmental Medicine, Yorkhill NHS Trust, Glasgow, G3 8SJ and* [2]*IBLS, The University of Glasgow, Glasgow, G12 8QQ*

In the UK an epidemic of childhood obesity occurred during the 1990s (Reilly and Dorosty 1999). The epidemic had a disproportionally large impact on children from families of lower socio-economic status (SES), but the cause of this SES difference is unclear. The aim of the present study was to test the hypothesis that habitual physical activity and inactivity differ between young children in association with SES. We studied thirty-nine pairs (n=78) of children aged 4–5 years old from upper and lower SES categories in Glasgow. SES was characterised for each family using the Carstairs Score, a geographically defined index based on postal sector of the family residence (Carstairs and Morris, 1991). The Carstairs Score is widely used in Scotland, and has been shown to denote marked and real differences in socio-economic circumstances and health outcomes (Carstairs and Morris, 1991). The Carstairs Score ranges from 1 (most affluent) – 7 (most deprived). The children were pair-matched for age, gender and season. Total physical activity and inactivity were measured for a minimum of 4 d and maximum of 7 d (mean 73.9 h, SD 12.3) using the Computer Science and Applications CSA WAM-7164 (MTI, Shalimar, Florida) accelerometer (Nilsson et al 2002). This accelerometer is practical for use with young children (Jackson et al 2003), and has high validity relative to the criterion method of direct observation of activity (Kelly et al 2003). Time spent in different intensities of activity was estimated using published cut-off points which allow accelerometry output to be defined as behaviour (sedentary behaviour, defined as <1100cpm (Reilly et al 2003), light intensity activity defined as ≥1101cpm to 3200cpm, moderate–vigorous physical activity ≥ 3201cpm, MVPA (Puyau et al 2002)). Paired t tests were used to assess the significance of differences in physical activity and inactivity between the two SES categories. Differences in total activity between the two groups (P<0.05) were significant in boys but not in girls.

However, these differences were small (affluent group mean 733cpm, SD 150.9; deprived group mean 763cpm, SD 176.4) and suggested slightly lower levels of total physical activity in the upper SES category relative to the deprived group. The more affluent boys were also slightly but significantly more inactive than the deprived group (percentage of time spent inactive by affluent group, mean 77.9cpm, SD 5.4; percentage of time spent inactive by deprived group, mean 73.3cpm, SD 6.2).

For the girls we found no significant differences between the two groups for any aspect of physical activity or inactivity. In both sexes and in both socio-economic groups engagement in MVPA was low (percentage of time spent in MVPA by affluent group, mean 3.4cpm, SD 1.6; percentage of time spent in MVPA by deprived group, mean 3.7cpm, SD 1.9). In conclusion, the present study does not support the hypothesis that young children from more deprived families are less active or more inactive than children from wealthier families. The low levels of engagement in moderate–vigorous physical activity in these young children should give serious cause for public health concern.

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Effect of Socio-economic Status on Habitual Physical Activity Inactivity in Young children measured by Accelerometry

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The worldwide obesity epidemic has been shown to have a disproportionally large impact on the children from families of lower socio-economic status (SES) but the cause of this SES difference is unclear. PURPOSE: to test the hypothesis that habitual physical activity and inactivity differ between young children in association with socio-economic status. METHODS: We recruited 39 pairs (n=78) of children (age 5.6 years; SD 0.4) from upper and lower SES categories. Socio-economic status was measured using the Carstairs score (Carstairs and Morris, 1990). The children were matched for age, gender and season. Total physical activity was measured for 7 days (mean 73.5 hours/wk; SD 12.4) using the CSA accelerometer. Time spent in different intensities of activity was estimated using published cut-off points. Paired t-tests were used to determine if there were differences between the two SES categories. RESULTS: In boys, total physical activity (expressed as accelermotery count per minute averaged over the entire recording period) was significantly higher in the deprived group (p-0.02). Time spent in inactivity was significantly higher in boys from the affluent group (p-0.01). In boys, time spent in light activity was significantly higher in the deprived group (p-0.01); however, there was no significant difference in the time spent in moderate or vigorous intensity activities between the groups. In girls, there was no significant difference in total physical activity, time spent in activities of different intensities or inactivity between the two groups. CONCLUSION: Our results were not consistent with the hypothesis that differences in physical activity/inactivity underlie socio-economic variation in obesity levels. Therefore an alternative explanation should be sought for the socio-economic difference in childhood obesity risk.

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Objectively measured physical activity and inactivity in rural Irish Children

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The recent obesity epidemic in children has led to an increased awareness of physical inactivity as a serious medical and public health concern (Reilly and Dorosty, 1999). However, to date there is a paucity of data on objectively measured physical activity and inactivity in contemporary populations of children. Young Irish children from rural areas might be expected to be more physically active than children from urban areas but there is no objective evidence to substantiate this hypothesis (Hussey et al., 2001). This study aimed to describe the levels of activity and inactivity in a sample of contemporary rural Irish Children.

Total physical activity (mean accelerometer count/minute), inactivity (% of monitored time below 1100 counts/minute; Reilly et al 2003), and time spent in light activity, and moderate-vigorous physical activity (MVPA) were assessed over 7 consecutive days using the Computer Science Applications accelerometer in a sample of rural Irish children (n= 41, 20 boys, mean age 5.3 SD 0.8.Engagement in sedentary behaviour was high: (mean 78% (SD 7) of total time. Boys spent significantly less time in sedentary behaviour (mean 75% (SD 7) vs. 81% (SD 5). Boys spent more time in light activity (mean 21% (SD 6) vs. 16% (SD 4) and MVPA (mean 4% (SD 2) vs. 2% (SD 1.4) behaviour.

This present study was the first to objectively measure physical activity and inactivity in Irish rural children. It suggests that contemporary rural Irish children are inactive and engagement in engagement in sedentary behaviour was as high as in age-matched children from urban Scotland. The amount of inactivity at this very young age is a major concern.

APPENDIX O

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Effect of Socioeconomic Status on Habitual Physical Activity and Inactivity in Young Children Measured Using Accelerometry.

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In the UK an epidemic of obesity occurred during the 1990's. The epidemic had a disproportionally large impact on the children from families of lower socioeconomic status (SES), but the cause of this SES difference is unclear. The aim of this study was to test they hypothesis that habitual activity and inactivity differ between young children in association with SES. We recruited 40 pairs (n=80) of children aged 4-5 (mean = years old from upper and lower SES Categories. The children were matched for age, gender and season. Total physical activity was measured for a minimum of 4 days and maximum 7 days (mean 76.8 hours/week SD 10.7) using the CSA accelerometer. Time spent in different intensities of activity was estimated using published cut-off points. Paired t tests were used to assess the significance of differences between the two SES categories. Data are currently available for 20 of the 40 pairs (9 pairs of boys and 11 pairs of girls). Differences in total activity ($p < 0.05$) and time spent in sedentary behaviour ($p<0.05$) were significant in boys but not girls. However, in boys differences were small and suggested lower levels of total physical activity in the upper SES category. This study suggests that differences in habitual activity and inactivity associated with SES are not related to obesity risk but further evidence is being obtained in order to increase study power.

ORIGINAL PAPER

Effect of socio-economic status on objectively measured physical activity

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Running title: Social patterning of physical activity

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Abstract

Background: A socio-economic gradient in childhood obesity is known to be present by the age of school entry in the UK. The origin of this gradient is unclear at present, but must lie in socio-economic differences in habitual physical activity, sedentary behaviour, or dietary intake.

Aims: To test the hypothesis that habitual physical activity and/or sedentary behaviour are associated with socio-economic status (SES) in young Scottish children.

Methods: Observational study of 339 children (mean age 4.2 years, SD 0.3) in which habitual physical activity and sedentary behaviour were measured by accelerometry over 6 days (study 1). In a second study we recruited 39 pairs of children of distinctly different SES (mean age 5.6 years, SD 0.3) and tested for differences in habitual physical activity and sedentary behaviour by accelerometry over 7 days.

Results: In study 1, SES was not a significant factor in explaining the amount of time spent in physical activity or sedentary behaviour once gender and month of measurement were taken into account. In study 2, we found no significant differences in time spent in physical activity or sedentary behaviour between affluent and deprived groups.

Conclusion: The present studies do not support the hypothesis that low SES in young Scottish children is associated with lower habitual physical activity or higher engagement in sedentary behaviour.

Licence for Publication

WHAT IS ALREADY KNOWN ON THIS TOPIC

Children from more socio-economically deprived families are at much greater risk of obesity than those from wealthier families.

The reasons for this social patterning in childhood obesity are unclear, but must lie in socio-economic differences in physical activity, or dietary intake, or both.

WHAT THIS STUDY ADDS

Habitual physical activity was not influenced by socio-economic status.

Socio-economic differences in obesity risk are likely to be due to social patterning of dietary intake.

Introduction

The obesity epidemic has affected even pre-school children[1,2] and, in the developed world, has had a disproportionately greater effect on more deprived families[3]. This socioeconomic gradient is evident by the pre-school years and persists into later childhood and adolescence[2,4,5].

Obesity is the result of a chronic energy imbalance (an excess of intake over expenditure), but the origin of socio-economic differences in this imbalance is unclear. A systematic review concluded that the evidence for socio-economic status (SES) differences in risk factors for obesity and heart disease in childhood was inconclusive and more research was required[6]. This review included many older studies, studies which were probably underpowered, studies which did not measure physical activity objectively, and which did not consider sedentary behaviour. Marked socio-economic differences in energy intake are not evident in dietary surveys in British children[2], but dietary intake assessment tends to be inaccurate and imprecise even in children[7]. With the advent of accelerometry, physical activity and sedentary behaviour (a distinct construct from physical activity which might be particularly important to obesity risk[8]) can be measured objectively in free- living children with relatively high precision and accuracy. Hypothesis testing as to the origin of early SES differences in obesity risk might, therefore, usefully be focused on measurement of physical activity and sedentary behaviour with accelerometry. Accordingly, the aim of the present study was to test whether there were significant differences in objectively measured habitual physical activity and sedentary behaviour in young children in relation to SES.

Subjects and Methods

Overall Design

We carried out two studies to test the hypothesis that habitual physical activity and/or sedentary behaviour differed between SES groups. In the first, we carried out an observational study (study 1) of SES and habitual physical activity and sedentary behaviour in children participating in the baseline stage of a randomised controlled trial, the 'MAGIC' study[8,9]. In the second study, children from families of high and low SES were paired (to control for gender, age, season, and school days/school holidays) and habitual physical activity and sedentary behaviour were compared between the two groups (study 2).

Subjects

Study 1.

We measured physical activity and sedentary behaviour in pre-school children (mean age 4.2 SD 0.5 y), with approximately equal numbers of children measured during the months of September and October 2002[9]. Children (n 382) were randomly selected for physical activity measurements from the larger sample participating in the baseline measurements of a randomised controlled trial (n 545)[9], and were eligible for the present study if they provided at least 6 hours per day of accelerometry over 6 days (n 339 of the 382 eligible). The children studied were broadly representative of Glasgow in terms of SES[9]. We assessed SES using the Carstairs Score, a geographically-based measure (based on a composite of social class, car ownership, unemployment, and overcrowded housing)[10]. This is a standard index of SES in Scotland, and has been shown to reflect marked differences in socio-economic circumstances and health outcomes[10,11]. The Carstairs Score uses seven categories, from 1 (most affluent) – 7 (most deprived). For study 1, we collapsed the seven categories to three (groups 1-2; 3-5; 6-7) and had physical activity data for 20, 93, and 226 children in each of the three groups respectively.

Study 2.

We recruited two groups of children of distinct SES, an affluent and deprived group (Carstairs scores 1-2 and 6-7 respectively). Children were recruited from year 1 of two distinct types of primary school: local authority (for Carstairs group 6 & 7) and private sector schools (for Carstairs group 1 & 2). Recruitment of children in this way not only facilitated selection of two distinct socio-economic groups, but the differences in education (local authority vs. private) reinforced the impression that these two groups were actually socio-economically distinct. Recruitment produced 116 children potentially available for inclusion. We included all children in deprivation categories 1 and 2 (affluent group) and deprivation categories 6 and 7 (deprived group) whom we could match pair-wise for gender and school days/school holidays, and our sample consisted of 78 children (39 pairs; 20 pairs of girls, 19 pairs of boys; mean age 5.6, SD 0.4 y) for study 2, all of whom provided at least 6 hours of accelerometry per day over 7 days during November.

For both studies 1 and 2, all children were apparently healthy, with no chronic disease relevant to energy balance or physical activity. The studies were approved by the Yorkhill Hospitals Ethics Committee. Informed written consent was obtained from the parent/ guardian of each child.

Measurements of habitual physical activity and sedentary behaviour

In study 1 we measured physical activity and sedentary behaviour objectively over 6 days during the waking hours (mean duration of measurement 54.9 hours SD 13.8) using accelerometers. In study 2 we measured the same variables over 7 days using the same methods (mean duration of measurement 73.9 hours, SD 12.3). In both studies we asked families to attach the accelerometers when the children woke up, to remove them when they went to bed, and to record when and why they were removed at other times. The accelerometers were set to monitor activity in 1-minute sampling intervals (epochs) as previously described[12]. These activity monitoring periods exceed the time required to determine usual physical activity and sedentary behaviour[13]. We have previously observed negligible day-to-day variation (e.g. weekday-weekend variation) in accelerometry output in our samples of young children in Scotland, and no systematic within-child, within day variation in accelerometry output (time of day effects)[12].

Accelerometry count averaged over the monitoring period (count per minute or cpm) was used as an index of total physical activity [12,14], and we also calculated % of monitored time spent sedentary (no trunk movement, <1100 cpm)[15], and % of monitored time in moderate-vigorous physical activity (MVPA; >3200cpm [16]). These definitions or 'cut points' for accelerometry output have been validated against both energy expenditure[16] and direct observation of behaviour[15] in previous studies.

Statistical analysis

Study 1

Analysis of variance and covariance models were used to assess the effect of the following explanatory variables on mean accelerometry output (cpm): age; BMI SD score; gender; SES; month of measurement. For each of these variables separately a univariate analysis was carried out. A final multivariate model was obtained by backward stepwise elimination from a model including all the five explanatory variables.

Study 2

Since study 2 used a paired design we tested differences between the two SES groups for significance using paired statistical methods. Our power calculation estimated that (with a paired design) a mean difference in total physical activity of around 100 cpm between groups would be detectable with 90% power at a significance 0.05, in 38-40 pairs of children. This magnitude of difference is approximately 10-15% of accelerometry output since this usually averages 700-800cpm[12,14,17]. For context, this difference in physical activity is of a similar magnitude to that typically observed between the sexes at this age[12,14,17]

Results

Physical characteristics of subjects, levels of physical activity and sedentary behaviour

The physical characteristics of children in both studies 1 and 2 are shown in **table 1.**

Study 1: Factors influencing physical activity

The results of the analysis are shown in **table 2.** A univariate analysis found that mean accelerometry output (cpm) was significantly lower in the most affluent SES group compared to the other two groups, but this association did not persist once other variables were taken into account in the multivariate analysis. Only gender and month of measurement were included in the final model in study 1. Total physical activity was significantly higher in boys than girls, and significantly higher in September than October.

Study 2: Differences in *total* physical activity between socio-economic groups

Total physical activity (accelerometry, cpm) did not differ significantly on average for affluent and deprived participants. Mean accelerometry count per minute in the affluent participants was 734 cpm (SD 151) compared with 793cpm (SD 196) for the deprived participants (Paired t test, $p = 0.10$). There were also no statistically significant differences in total physical activity between affluent and deprived participants when considered separately by gender ($p > 0.05$ in each case).

Study 2: Differences in *moderate-vigorous intensity physical activity* between socio-economic groups

Median % of monitored time spent in moderate to vigorous intensity activity (MVPA) was identical in the affluent and deprived participants: 3% (range 1-7) vs. 3% (range 1-9) respectively.

Study 2: Differences in *sedentary behaviour* between socio-economic groups

Median % of monitored time spent in sedentary behaviour was not significantly different for the two groups (affluent participants, 79% (range 68-90) vs. 78% (range 67-89) for the deprived participants (Wilcoxon Sign Rank test, $p = 0.13$).

When data were analysed separately by gender, we found that in boys % time spent in sedentary behaviour was significantly *lower* in the deprived than the affluent group (Wilcoxon Sign Rank test, $p=0.01$). For all other analyses of physical activity and sedentary behaviour results did not differ when analysed with the entire group or by gender.

Discussion

In the present study we found no evidence of marked differences in either habitual physical activity or sedentary behaviour between SES groups. Thus, our observations do not support the hypotheses that more deprived children are less physically active or more sedentary than more affluent children, despite marked differences in obesity risk associated with SES[2,4,5]. Our failure to observe differences in physical activity and sedentary behaviour in the predicted direction could relate to lack of power, but with the paired design study 2 was powered to detect quite small differences in engagement in total physical activity (100 cpm between groups) - differences that may be too small to be biologically meaningful [12,14,15,17]. Study 1 was amongst the largest study to use objective methods to measure physical activity in pre-school children to date.

The present study suggests that social patterning of childhood obesity in the UK may be due to socio-economic differences in dietary intake rather than differences in habitual physical activity or sedentary behaviour. This perspective on the aetiology of obesity is reductionist as it considers the origin of obesity purely from the point of view of energy balance, the difference between energy input and output. We accept that the aetiology of obesity is more complex than this in reality, and that research which considers the many possible behavioural or biological determinants of socio-economic differences in obesity will be helpful in providing an improved understanding of its social patterning in future.

At present very few studies have reported on *objectively* measured physical activity and sedentary behaviour in young children. The determinants of physical activity in childhood remain unclear[18,19] and SES has not emerged strongly as a predictor of physical activity in the literature[19]. Predictors of objectively measured sedentary behaviour in young children are even less well understood since this topic has been little researched, only emerging in the literature as an important variable relatively recently [8,15].

The cut-offs we applied to accelerometry output to determine time spent in different intensities of activity have been validated against direct observation of behaviour and energy expended on activity in children in independent studies[15,16], and so should have provided accurate measurement of time spent sedentary and in MVPA. However, it is possible that subtle differences in the *types* of activity undertaken by children in different socio-economic groups, not measured by accelerometry, might be important. It is also possible that habits associated with sedentary behaviour (such as eating/snacking while watching TV)[20] might have differed between the socio-economic groups, but these would not have been identifiable using accelerometry. Short sleep duration has recently been suggested as a possible risk factor for childhood obesity[21], and it is conceivable that this might differ between socio-economic groups, but we did not set out to measure sleep duration precisely in the present study, or to power our study to detect differences in sleep duration between groups.

In the present study we considered habitual physical activity and sedentary behaviour as separate constructs, as is now the norm[8,15]. However, we accept that in circumstances where one form of behaviour (in this case sedentary behaviour) predominates, this may displace opportunities for other forms of behaviour such as moderate-vigorous physical activity[14,17,22].

It is possible that there are differences in habitual physical activity between ethnic groups in the UK, or that relationships between physical activity and adiposity might differ between ethnic groups, or between boys and girls. Children who participated in the present studies were almost entirely from the majority ethnic group in Scotland, and so we could not address the issue of ethnicity. We found evidence that social patterning of sedentary behaviour might differ between boys and girls in study 2, but this needs to be confirmed in future studies in other samples and settings. One recent study found a possible gender difference in the relationship between physical activity and adiposity in 7 year old British children.[22]

In the present studies, we used a uniaxial accelerometer (i.e. designed to measure activity predominantly in the vertical plane). While in theory measurement in two or three planes of movement might provide greater accuracy, empirical studies comparing uniaxial vs bi or triaxial accelerometry do not support this [23,24]. We summarised accelerometry output in 1-minute measurement intervals (epochs). In theory, shorter epochs might provide more accurate quantification of more vigorous activities, but again empirical tests do not support this hypothesis, and use of shorter measurement intervals does not provide an advantage in practice[25]. The main practical impact of this approach to the interpretation of accelerometry output appears to be a small systematic misclassification of some vigorous activity as moderate intensity activity[25] and this is one reason why we summarised both categories in combination.

Conclusions

The results of the present studies are not consistent with the hypothesis that differences in physical activity or sedentary behavior underlie socio-economic variations in obesity risk in early childhood. The present leads to the prediction that socio-economic differences in dietary intake underlie the social patterning of obesity in young British children.

Acknowledgements

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Table 1. Characteristics of Participants, Physical Activity and Sedentary Behaviour (Mean, SD*)

(Study 1, n 339; Study 2, n 78)

Characteristic	**Study 1**	**Study 2**
Age (years)	4.2 (0.3)	5.6 (0.4)
BMI SD score	0.40 (0.89)	0.61 (0.73)
% time spent sedentary*	77 (53-93)	78 (67-90)
% time spent in moderate-vigorous* physical activity	3 (0-13)	3 (1-9)

*Variables with skewed distribution, so median (range) given

Table 2. Analysis of Variance and Co-variance for Study 1 (total physical activity, mean accelerometer count per minute)

Explanatory Variable	Univariate Analysis		Multivariate Analysis	
	Co-efficient (ESE)*	P value	Co-efficient (ESE)*	P value
Gender, Female vs. Male	-62.0 (20.7)	0.003	-59.1 (20.3)	0.004
Month (October vs. September)	-83.9 (20.7)	<0.0005	-81.8 (20.5)	<0.0005
SES, 1 vs. 3	-124.5 (44.6)	0.02	-	-
SES, 2 vs. 3	-1.8 (23.6)	ns**	-	-
Age (years)	16.3 (30.1)	ns	-	-
BMI SD score	17.4 (11.2)	ns	-	-

Footnotes:

R squared for final model, 7.0%.

*ESE, estimated standard error.

**ns, not significant.

Low physical activity levels and high levels of sedentary behaviour are characteristic of rural Irish primary school children

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Abstract

There is increasing public health concern that levels of physical activity in children are extremely low. This study aimed to describe objectively levels of physical activity and sedentary behaviour during the waking hours in a sample of 4-5 year old (median 5.4 years range 4.3, 6.0) rural Irish children (n=41) and to test for gender differences in patterns of physical activity and sedentary behaviour. There were significant gender differences in physical activity (Boys (median) 834 accelerometer counts per minute (cpm), girls (median) 628cpm; p = 0.0015), sedentary behaviour (Boys 74% of waking time, girls 81% of waking time, p=0.0011) and moderate-vigorous physical activity (Boys 4% of waking time, girls 2% of waking time; p=0.0175). This study that suggests young rural Irish children lead sedentary lifestyles.

Keywords: MTI/CSA accelerometer; children; physical activity

INTRODUCTION

The childhood obesity epidemic in Britain and the rest of the world[1] has led to increased awareness of low physical activity as a serious public health concern[2]. Low physical activity levels and high levels of sedentary behaviour appear to be characteristic of pre-school children in the UK, [3,4,5] and there is evidence of high engagement in TV viewing in Irish children[6]. Low levels of physical activity may predispose children to obesity and other chronic diseases in later life[7].

Measurement of physical activity and sedentary behaviour is useful for treatment and prevention of childhood obesity[3] and has been carried out in children in the UK and the USA. Studies show that young children are inactive[3,4,5]. There is a paucity of information on physical activity and sedentary behaviour, and consequences of sedentary behaviour[4,8] in young Irish children. Consequently there is a need to determine activity levels to provide baseline information. Accelerometry provides a practical and accurate means of objectively assessing engagement in physical activity[7-9] and sedentary behaviour[10] in young children[4,9,11,12]. The aims of the present study were to describe physical activity and sedentary behaviour of young rural Irish children and test for gender differences in physical activity and sedentary behaviour.

METHODS

Subjects, Design, and Analysis

The subjects were healthy rural Irish children recruited in 2003. A list of national primary schools in County Carlow, Ireland was obtained from the Carlow County Council. The list consisted of 42 schools suitable for inclusion (excluding schools for children with special needs). The Head Teacher of each school (n=42) was contacted by mail with a detailed explanation of the study. Written consent was obtained from 8 rural schools willing to participate in the study. Recruitment letters (detailing the study in full) and consent forms for all parents of the 212 children in junior Infants were sent to the school. A total of 53 families consented to participate in the study, 41 subjects were included in the final analysis. Socio-economic status (SES)[13] of the sample was compared with that of Co. Carlow, Ireland using a chi-squared test. Measurements of BMI, habitual physical activity and sedentary behaviour by accelerometry were carried out in these 41 subjects. The local Ethics Committee approved the study. Informed written consent was obtained by the parent/guardian of each child.

Measurement of Physical Activity and Sedentary Behaviour

Habitual physical activity and sedentary behaviour were measured using the MTI/CSA WAM–7164 accelerometer (MTI, Fort Walton Beach, Florida, USA). This is a small, lightweight, uniaxial device (measures movement in the vertical plane) which was worn on the right hip under clothing as previously described[3,4,10,14].

Studies have reported favourably on the validity of the MTI/CSA accelerometer in children, by comparisons against direct observation of behaviour or energy expenditure[9,10,14-17]. For inclusion in the analysis, activity and sedentary behaviour were monitored for 7 consecutive days for a minimum of 6 hours per day[4]. Families were instructed to put the accelerometer on their child in the morning and remove it before bedtime and note in a diary the times the accelerometer was put on and taken off (e.g. bathing). Measurements were made during February 2003.

Interpretation of Accelerometer Data

The MTI/CSA accelerometer produces 'raw' output in activity counts per minute (cpm), which can be considered as a valid index of total 'volume' of physical activity[7, 11]. Alternatively, accelerometry output can be interpreted using age specific cut-points, which describe different intensities of physical activity[10,14]. Paediatric cut-points have been published recently which have been validated for young children carrying out free-living activities based on both of the criterion measures for physical activity, i.e. energy expenditure[10] and direct observation of behaviour [10,14]. In the present study we used: sedentary behaviour <1100 cpm[14], light intensity activity 1100-3200 cpm[10], moderate and vigorous physical activity (MVPA) >3200 cpm[10] as the cut-points.

Anthropometry

Height was measured using the Leicester height measure to 0.1 cm, and body mass using TANITA scales (to 0.1kg). Body mass index (BMI) was calculated as weight (kg)/height (m^2). BMI was expressed as a standard deviation score (SDS) relative to 1990 UK reference data[18].

Statistical analysis

All data were checked for normality prior to statistical analysis using descriptive statistics, histograms with normal distribution curves and using Anderson-Darling (A.D) normality tests. As all anthropometric, physical activity and sedentary behaviour data were non-parametrically distributed (Anderson Darling $p < 0.05$), a Kruskall-Wallis test was used to determine if there were any differences in anthropometric measures, physical activity and sedentary behaviour. A chi-squared test was used to determine any SES differences between the sample and Co. Carlow, Ireland. Follow-up pair wise Mann-Whitney U tests were used to determine where these differences lay.

RESULTS

Physical Characteristics of Subjects

Satisfactory accelerometry measurements were obtained in 41 (20 boys and 21 girls) of 53 children recruited. The remaining 12 subjects were excluded from the study as they either refused or were absent from school on the appointed measurement days. Anderson-Darling normality testing showed skeweness in the data for age (yrs), height (m), weight (kg), body mass index (BMI: kg/m^2), and BMI standard deviation score. The characteristics of the 41 children (median age 5.4 years range 4.3–6.0) are shown in **table 1**. The 41 children did not differ significantly for body mass index (Mann-Whitney U test p=0.96), or body mass index standard deviation score (an index of under and overweight), relative to UK 1990 reference data[18] (Mann-Whitney U test p=0.42). Median duration of activity and sedentary behaviour monitoring for all children included in the analysis was 76.6 hours (range 42.2, 83.3 hours). Participants were broadly representative of Carlow, Ireland in terms of socio-economic status (chi-squared test, p = 0.36).

Habitual Physical Activity

Total physical activity was expressed as accelerometry count per minute (cpm), averaged over the entire recording period. Physical activity characteristics of the children are presented in **table 2**. Median total physical activity for the group was 726cpm (range 395, 1287cpm). Boys had a significantly higher total physical activity than girls (Mann-Whitney U test p= 0.0015; 95% CI = 79, 269cpm).

Light Intensity Physical Activity

As a group, Irish rural children spent a median of 19% (range 10, 40%) of their time in light intensity activity. Median time spent by boys in light intensity activity was 20% (range 12, 40%). Girls spent a median 16% of time (range 10, 24%) in light intensity activity (**Table 2**). Boys spent significantly more time in light intensity physical activity than girls (Mann-Whitney U test p = 0.0031; 95%CI = 2, 7%).

Moderate-Vigorous Intensity Physical Activity (MVPA)

The median percent of monitored time spent in MVPA was 3% (range 1, 8%). Girls spent 2% (range 1, 6%) of their time in this activity intensity, whereas boys spent 4% (range 1, 8%) of their time engaging in MVPA (**Table 2**). Boys spent significantly more time in MVPA than girls (Mann-Whitney U test p= 0.0175; 95% CI = 0, 3%).

Sedentary Behaviour

The median percent of monitored time spent in sedentary behaviour was 78% (range 53, 89%; **Table 2**). Girls spent 82% (range 74, 89%) of the monitored time in sedentary behaviour. Boys spent 74% (range 53, 87%) of time in sedentary behaviour. Boys spent significantly less time in sedentary behaviour than girls (Mann-Whitney U test p= 0.0011; 95% CI = -9, -2%.

DISCUSSION

This study was the first to use objective methods to quantify habitual physical activity in young rural Irish children. Irish children in this study demonstrated high levels of sedentary behaviour. Time spent in sedentary behaviour during the waking hours was 78% (median), and only 3% (median) of the day was spent in MVPA. Over a 12-13 hour waking day this would represent around 19-25 minutes of MVPA, much less than the 60-minute per day now recommended for children[19]. It is of great concern that the Irish rural children did not engage in the recommended amount of moderate-vigorous physical activity necessary for health during the day despite their young age and rural environment. This study also suggests that the gender difference in engagement in physical activity and sedentary behaviour, commonly demonstrated in adolescents, is present from a young age.

Comparison of the results of the present study with the limited research on physical activity and sedentary behaviour in Irish children is difficult, as the previous studies have used activity questionnaires on older age groups. Hussey et al reported high levels of sedentary behaviour in 7-9 year old children (n= 786, 352 boys, 434 girls) in Dublin [6]. They found that 39% of children reported participating in vigorous activity for at least 20 minutes three or more times a week. However 78% of children reported spending three or more hours a day sedentary in front of a television screen[6]. O'Sullivan[20] reported Irish urban primary school children (n=1,602, aged 11-12 years), appear to spend less time "in sedentary behaviours" than other European populations and also report a higher percentage of "active" and "highly active" children among rural children [20]. The authors suggested that the use of a questionnaire might have resulted in over reporting of physical activity[20].

Observations of sedentary behaviour in young children in rural Ireland have been reported other settings[3,4,10,11,12,17]. There is increasing speculation that contemporary children may be more sedentary than in the recent past, and that our observations are not atypical. Strauss and colleagues[21] reported low levels of MVPA in a sample of US urban children, and parental reports of TV viewing by pre-school children in the US suggest that high levels of sedentary behaviour is also common[22].

This study had a number of limitations. First, the extent to which the results observed are generalisable to other settings or populations is unclear and warrants investigation. The uni-axial accelerometer used in this study in principle should provide less accurate measurement than bi-or tri-axial instruments. However, in practice this might be trivial, so long as a valid calibrated uni-axial instrument is used. Published studies suggest that uni-axial accelerometers have a high degree of accuracy[10,23,24]. The uni-axial MTI/CSA accelerometer used in this study has high validity relative to direct observation of behaviour and energy expenditure as criterion measures[9,10, 14-17]. Validated paediatric cut-points for measurements of both free-living activity and sedentary behaviour are only available for this accelerometer [10,14]. Finally, it has been argued that shorter epochs might measure vigorous intensity activity more accurately. The empirical evidence suggests that this is only a relatively minor source of error, with the main consequence of using 1-minute epochs being a very slight misclassification of some vigorous activity as moderate intensity activity[25]. For the present study we combined categories of 'moderate and vigorous' intensity physical activity, in practice this made little difference since the total time spent in the combined category was so small.

This study found low levels of engagement in moderate-vigorous physical activity and high engagement in sedentary behaviour in 5-year-old rural children in Ireland. Gender differences in engagement in physical activity and sedentary behaviour in modern children, commonly described in adolescents and adults, are present even at this young age.

This study also suggests that young Irish children are not "protected" from sedentary behaviour by being children or living by living in a rural setting. Public health interventions should be considered to address this problem and these must involve population-based strategies to increase physical activity and/or decrease sedentary behaviour in early life.

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Table 1 Characteristics of Subjects (median and range)

Variable	Group (n=41)	Boys (n=20)	Girls (n=21)
Age (years)	5.4 (4.3, 6.0)	5.3 (4.3, 6.0)	5.5 (4.7, 6.0)
Weight (kg)	21.8 (14.7. 31.0)	21.1 (18.3, 31.0)	21.9 (14.7, 27.3)
Height (m)	1.13 (1.01, 1.21)	1.13 (1.07, 1.21)	1.13 (1.01, 1.20)
BMI ($Kg{\cdot}m^2$)	17.1 (14.5, 22.9)	17.0 (15.3, 22.9)	17.1 (14.0, 19.8)
BMI SDS*	1.0 (-0.7, 3.6)	1.1 (-0.2, 3.6)	1.0 (-0.7, 2.3)

* BMI expressed as a standard deviation score (SDS) relative to the UK 1990 reference data as an index of under/overweight (18)

Table 2. Physical Activity Characteristics for Irish Rural Children (median and range)

Variable	Group (n=41)	Boys (n=20)	Girls (n=21)
Total Physical Activity (cpm)	726 (395, 1287)	834 (490, 1287)	628 (395, 823)
Total Hours Monitored (hours)	76 (42, 84)	75 (42, 84)	77 (58, 84)
% Time Spent Sedentary	78 (53, 89)	74 (53, 87)	82 (74, 89)
% Time Spent in Light Activity	19 (10, 40)	20 (12, 40)	16 (10, 24)
% Time Spent in MVPA*	3 (1, 8)	4 (1, 8)	2 (1, 6)

* MVPA Moderate to Vigorous Physical Activity