Video Gaming, Physical Activity and Health in Young People

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A thesis submitted in partial fulfilment of the
requirements of Liverpool John Moores University
for the degree of Doctor of Philosophy

March 2010

Liverpool John Moores University

Candidate declaration form

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Abstract

Increasing physical activity (PA) and reducing the time spent sedentary can favourably impact health in youth. Active video games discourage sedentary behaviour by incorporating PA into video gaming, and have the potential for increasing opportunities for, and the promotion of, PA. The aims of this thesis were to a) compare adolescents' energy expenditure (EE) whilst playing sedentary and active video games; b) to examine the contribution of upper limb and total body movement to adolescents' EE whilst playing non-ambulatory active video games; c) to compare the physiological cost and enjoyment of active video gaming with sedentary video gaming and aerobic exercise in adolescents, and young and older adults; and, d) to evaluate the short-term (12 weeks) effects of a home-based active video gaming intervention on children's habitual PA and sedentary time, behaviour preferences, and, body composition, with a mid-test analysis incorporated at 6 weeks.

The first three studies were cross-sectional. They revealed that active video games significantly increased PA and EE compared with sedentary video games in adolescents. These increases were typically of insufficient intensity though to contribute towards recommendations for daily PA in youth, and were less than those observed for authentic sports and brisk treadmill walking and treadmill jogging. Nevertheless, active video games encouraged PA and discouraged sedentary behaviour compared to sedentary equivalents. Further, similar physiological responses observed between adolescents and adults in study three provided support for the promotion of active rather than sedentary video gaming throughout the lifecourse. Greater enjoyment of active video games compared to a sedentary video game and brisk treadmill walking and treadmill jogging suggested that active video games may be an enjoyable mode of entertainment for young people and adults. The methodologically-focused study two revealed that the best single measure for explaining the variance in EE during active video gaming was a hip-mounted accelerometer. This was congruent with current recommendations for measuring habitual PA using accelerometers. Interestingly, using combined PA data from accelerometers placed on the hip and wrist similarly explained the variance in EE during active gaming compared to combined HR and activity monitoring. This provided support for the assessment of upper limb movements during non-ambulatory activities in adolescents.

The intervention study revealed that a targeted increase in active video gaming and decrease in sedentary video gaming at 6 weeks did not positively affect children's PA relative to an age-matched comparison group. An increase in total video gaming was observed at 6 and 12 weeks relative to the comparison group, and this was accompanied by non-significant but detrimental changes in PA compared to the comparison group. These findings may suggest that an increase in time spent playing video games may be detrimental to PA in children. Rather than simply enabling PA by providing active video gaming equipment, interventions that consider the wide range of PA and sedentary behaviour opportunities available to young people in the home environment may be necessary to benefit PA and health. Further, the novelty effect observed for active video game use supports the call for the production of new active video games that attract children and sustain their interest.

Acknowledgements

I would like to greatly thank Professor Gareth Stratton for providing me with the opportunity to pursue my aim of making a difference to the lives of young people. I thank Gareth for his continual support over recent years. His knowledge, experience and guidance have been pivotal in my early years as a researcher and the formation of this thesis. I thank Professor Greg Atkinson for his invaluable, reassuring advice on the murky world of statistics. I thank Dr Warren Gregson for his invaluable contributions throughout the PhD process.

I would like to make special thanks to my unofficial supervisor, Dr. Nicola Ridgers. Nicky has provided unprecedented support and guidance. Most notably her help during testing times and advice on the game that is peer-reviewed publications has been pivotal. Though her efforts will not be formally recognised, I regard her contributions to this thesis as vital.

To my other friends and colleagues I would like to say a massive thank you for your encouragement, reassurance and positivity. Special acknowledgment goes out Nicky Mac, Jayne, Jackie, Niki Hop and Loz for the good times that were the A-CLASS Project. We kept each other sane and managed to have fun along the way. Thanks to the lads of Pete, Ham and Tim for your day-to-day support and friendship. Thanks team.

Finally, I would like to further thank Niki and my family. Niki, your love and support have been amazing and I am truly grateful for it. Thank you for making me smile each day and radiating your enthusiasm for life on me. To my family, especially Mum, Dad and Liana, thank you for your continual support, encouragement, wise words and love. I look up to you all and am proud to be your son and sibling.

Remember...be active!

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Glossary of Terms

Children	This term covers the chronological age range 4 to 11 years.
Adolescents	Chronological age range 12 to 17 years.
Young adults	Chronological age range 18 to 40 years.
Older adults	Chronological age over 40 years.
Sedentary behaviour	No unanimous definition exists for sedentary behaviour. It has been described as the absence of physical activity and involves the intentional engagement in mostly seated activities that require minimal movement and low energy expenditure (Biddle et al., 2004a; Reilly et al., 2003). Within this thesis, sedentary behaviour will be objectively defined as accelerometer activity counts per minute (CPM) less than or equal to one hundred (Treuth et al., 2004).
Physical activity (PA)	Defined as 'any bodily movement produced by skeletal muscles resulting in energy expenditure' (Caspersen et al. 1985, p. 126).
Light intensity physical activity	Corresponds to energy expenditure between 1 and 3 times that used at rest, or 1 and 3 metabolic equivalents (Freedson et al., 1998).
Moderate intensity physical activity	Defined as 'activity usually equivalent to brisk walking, which might be expected to leave the participant feeling warm and slightly out of breath' (Biddle et al., 1998, p. 2). Corresponds to energy expenditure between 3 and 6 metabolic equivalents (Freedson et al., 1998).
Vigorous intensity physical activity	Defined as 'activity usually equivalent to at least slow jogging, which might be expected to leave the participant feeling out of breath and sweaty' (Biddle et al., 1998, p. 2). Corresponds to energy expenditure between 6 and 9 metabolic equivalents (Freedson et al., 1998).
Very vigorous intensity physical activity	Corresponds to energy expenditure greater than 9 metabolic equivalents (Freedson et al., 1998).
Moderate to vigorous intensity physical activity (MVPA)	Physical activity of intensity equivalent to or greater than moderate intensity ($\geq$ 3 metabolic equivalents).

Exercise	A subset of physical activity defined as 'planned, structured, repetitive and purposive in the sense that improvement or maintenance of one or more components of physical fitness is an objective' (Caspersen et al., 1985, p. 128).
Active video games	No unanimous definition exists. Active video games incorporate exercise into video gaming through peripheral devices or the video game itself, with the latter referred to as an exergame.

Chapter 1

Introduction

Introduction

1.1 The research problem

The World Health Organisation (1946) defined health as 'a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity' (p.100). A behaviour that can favourably modify health is physical activity (PA). Physical activity has been defined as 'any bodily movement produced by skeletal muscles resulting in energy expenditure (EE)' (Caspersen et al., 1985, p. 126). While PA has common elements with exercise, the terms are not synonymous. Exercise is a subset of PA that is, 'planned, structured, repetitive and purposive in the sense that improvement or maintenance of one or more components of physical fitness is an objective' (Caspersen et al., 1985, p. 128). Physical fitness is, 'a set of attributes that people have or achieve that relates to the ability to perform physical activity' (Caspersen et al., 1985, p. 129). Physical fitness attributes include cardiorespiratory endurance, muscular endurance, muscular strength, body composition and flexibility (health-related), and, agility, balance, coordination, power, reaction time and speed (skill-related) (Caspersen et al., 1985).

Higher levels of PA in children and adults are associated with fewer risk factors for disease (Andersen et al., 2006), and, decreased morbidity and delayed mortality (Blair et al., 1989; Paffenbarger et al., 1986), respectively. Young people and adults are therefore recommended to engage in at least 60 and 30 $min{\cdot}d^{-1}$ of moderate to vigorous intensity PA (MVPA), respectively (Health Canada, 2002; Australian Government, 2005; Department of Health (DH), 2004). Moderate intensity PA corresponds to an EE above or equal to three times the energy used at rest, referred to as 3 metabolic equivalents (METs; Freedson et al., 1998). Despite these PA recommendations, there is concern that many children and adults are insufficiently active to benefit their health (Riddoch et al., 2007; Varo et al., 2003). Moreover, the level of overfat and obesity in young people and adults is rising worldwide, especially within industrialised countries (Chinn and Rona, 2001; Ogden et al., 2006).

Many factors are suggested to contribute to low levels of PA and energy imbalance in youth. These include low social and economic support from parents (Duke et al., 2003), low PA self-efficacy (Van der Horst et al., 2007), technological advancements that encourage motorised transport and seated activities such as television (TV) viewing, and, low parental perceptions of outdoor or environmental safety (Spanier et al., 2006; Biddle et al., 1998). Consequently, the promotion of PA in young people has become a public health priority (Biddle et al., 1998).

There are many suitable settings within which PA promotion can occur. This includes the indoor and outdoor home environment, the school environment, sports facilities, and, community hall and play areas (Owen et al., 2000). The home is an important setting within which PA can be encouraged and fostered, as young people spend a substantial proportion of the day at home where parents can reinforce positive behaviours (Owen et al., 2000). Many elements inside and outside the home may influence PA in youth. Time spent outdoors is positively correlated with PA in children aged 3 to 12 years old (Sallis et al., 2000). In relation to the home environment, living in a cul-de-sac or court is associated with greater time spent by children playing in the street rather than in a park or yard (Veitch et al., 2006). Parents suggested this was due to safety and social elements including other children to play with (Veitch et al., 2006).

In contrast, low parental perceptions of environmental safety, especially in low socio economic status (SES) communities, is thought to result in parents encouraging children to spend time in the home rather than outside (Goodway and Smith, 2005; Farley et al., 2007). This is supported by research indicating that time spent engaged in sedentary screen-based behaviours such as watching TV and playing video games is inversely associated with SES (Gorely et al., 2004; Jago et al., 2008; Fairclough et al., 2009). No clear definition exists for sedentary behaviour. However, it has been described as the absence of PA and involves the intentional engagement in mostly seated activities that require minimal movement and low EE (Biddle et al., 2004a; Reilly et al., 2003). Low income or single parent families may also encourage children to engage in sedentary behaviours as they require low parental input and present a cheaper option to other leisure activities (McElroy, 2008; Larson and Verma, 1999). Thus, it has been suggested that interventions are needed to address such inequalities in the prevalence of sedentary behaviour and PA participation (Fairclough et al., 2009).

The time young people spend sedentary in the home presents an opportune period within which PA can be promoted. Sedentary behaviours young people engage in within the home are typically screen-based, such as TV viewing and video game or computer use (Marshall et al., 2006). Whilst some children can meet PA recommendations and spend large amounts of time in sedentary behaviours (Marshall et al., 2002), objectively measured sedentary time, defined as accelerometer activity counts less than 500 counts per minute (CPM), has been associated with individual and clustered metabolic risk in a large sample of European youth (Ekelund et al., 2007). Spending more than 2 $h{\cdot}d^{-1}$ watching TV and playing video games was also found to be associated with a greater risk for overweight in youth compared to spending less than 2 $h{\cdot}d^{-1}$ watching TV and playing video games (Spinks et al., 2007; Laurson et al., 2008). Moreover, sedentary behaviours including TV and video game use are reported to track at moderate levels during childhood (Janz et al., 2005) and from childhood to adolescence (Pate et al., 1999). The probability of remaining sedentary (spending ≤ 1 $h{\cdot}wk^{-1}$ in light intensity PA) from adolescence to young adulthood has also been found to be stronger than the probability of remaining physically active (physically active cut point included spending ≥ 2 $h{\cdot}wk^{-1}$ in intense PA) (Raitakari et al., 1994). Thus, reducing the time young people spend sedentary is important for current and future health, with screen-based behaviours in the home suitable to target.

When considering PA promotion in the home it is important to appreciate that young people are content to spend prolonged periods in sedentary screen-based behaviours. Screen-based behaviours are insidiously attractive (Pate, 2008), continually stimulating (Vorderer et al., 2004; Sherry, 2004), and often present an opportunity to escape from reality (Wood et al., 2007). While previous interventions attempting to promote PA through a reduction in access to sedentary behaviours have been successful in preventing weight gain (Robinson, 1999), there is evidence that reducing access to screen-based media is met with resistance from youth (Faith et al., 2001; Wilson, 2007). Further, the long-term sustainability of reducing access to sedentary behaviours is questionable, as young people enjoy screen-based media, screen-based entertainment is embedded in our culture, and, sedentary entertainment options have proliferated (Pate, 2008).

It has been suggested that to promote PA in the context of contemporary society, innovative interventions need to use technology for active movement (Olds et al., 2004; Pate, 2008). This could be achieved by incorporating PA into the sedentary screen-based behaviours young people enjoy (Mellecker et al., 2008). If this was achieved and young people chose to engage in a targeted screen-based behaviour in an active rather than sedentary manner regularly over time, then increased PA and EE is inevitable, and may confer health benefits and lower childhood obesity rates (Pate, 2008). Attempts to use technology to incorporate PA in sedentary screen-based behaviours in the home are supported by research indicating that access to PA and exercise equipment in the home is positively associated with PA in children (Trost et al., 2001).

Active video games incorporate PA into video gaming and have the potential for increasing opportunities for, and the promotion of, PA in the home. Active video games also discourage sedentary behaviour. The opportunity to play video games in an active manner has emerged due to the production of peripheral devices such as dance mats, camera technology or wireless hand-held controllers. In essence, rather than pushing buttons on a video game controller, the body movements of a gamer manipulate onscreen characters or objects during active video gaming. Active video game devices are designed for use on commercially available video game consoles, and, game play typically requires a small area in front of a TV or computer monitor. The availability of space in the home and cost of active video game devices may be barriers to participation, though devices are generally low cost if the console is already owned. Attempts to convert video gaming from sedentary to active may therefore be a useful way of increasing PA in young people, especially from lower SES groups, as it can avoid barriers to PA such as parental fear of environmental safety, low time availability and low socio and economic support from parents.

There is little evidence of the level of use of active video games in the home over time, and, the effects of active video games on PA, sedentary behaviour and health in young people. In addition, few studies have investigated the PA levels of young people during active video gaming. Quantifying PA and EE during active video gaming will inform whether these devices, if they were to replace sedentary video games, could contribute to energy balance and weight management. Whether active video gaming contributes to daily PA recommendations can also be determined. Comparing PA levels between young people and adults during active video gaming would also provide an indication as to whether similar physiological responses occur regardless of age. If similar physiological responses were observed across different age groups, this would support the promotion of active rather than sedentary video gaming throughout the lifecourse. Few studies have also investigated whether individuals enjoy playing active video games. Research in this area would inform the potential application of active video games in PA promoting interventions.

1.2 Conceptual model to increase youth physical activity

Theories or conceptual models can be used to drive the effective development and implementation of intervention programs to increase PA in young people. For PA promotion, a theory or conceptual model should be created based on research indentifying correlates or determinants of behaviour change in the targeted population (Nigg and Paxton, 2008). Determinants have been referred to as 'reproducible associations that are potentially causal' (Buckworth and Dishman, 2002, p. 191) rather than necessarily causal effects (Biddle et al., 2004b). To date, two comprehensive reviews by Sallis et al. (2000) and Van der Horst et al. (2007) on manuscripts up to 1999, and between 1999 and 2005, respectively, have investigated correlates of PA in children and adolescents.

In both reviews, gender was consistently related to PA, with boys more active than girls throughout youth (Sallis et al., 2000; Van der Horst et al., 2007). Thus, targeting girls in PA promoting interventions is important. Sallis et al. (2000) found positive associations between PA and previous PA in children and adolescents, and, access to facilities and preferences for PA in children. Barriers to PA were also negatively correlated with PA in children (Sallis et al., 2000). Thus, increasing PA from an early age is important, and interventions that increase access to facilities and children's liking of PA, which may also reduce barriers to PA, may be effective. Interestingly, similar associations were not reported by Van der Horst et al. (2007). This may be due to fewer studies being included in the Van der Horst et al. (2007) review and some variables being studied more often in a certain period. Van der Horst et al. (2007) instead found positive associations between PA and PA self-efficacy and family/parental support in children and adolescents. This suggested that increasing a young person's belief in their capability to engage in PA is important, and, greater family support, such as transporting children to activities or reinforcing PA, may increase PA and further develop PA self-efficacy.

In contrast to the vast literature on correlates of PA, few studies have investigated correlates of sedentary behaviour (Nigg and Paxton, 2008). Van der Horst et al. (2007) concluded that insufficient evidence was available to draw conclusions for correlates of TV, videotape and computer use in children. However, the review was limited by using few search terms that did not include TV viewing and computer use (Van der Horst et al., 2007). In adolescents, for whom more studies were included, Van der Horst et al. (2007) reported negative associations between TV/video tape use and SES and parental education. This suggested that youth from lower SES groups should be targeted for interventions attempting to reduce sedentary behaviour, similar to previous research (Gorely et al., 2004; Jago et al., 2008; Fairclough et al., 2009). Interestingly, neither the Sallis et al. (2000) nor Van der Horst et al. (2007) review found an association between PA and sedentary behaviour. This suggested that correlates for PA and sedentary behaviour are likely different (Biddle et al., 2004b) and these behaviors can coexist within the lives of young people (Owen et al., 2000).

A major limitation of the available literature is how sedentary behaviour is assessed. Rather than isolate specific sedentary behaviours many studies use TV viewing alone or composite variables that include TV, videotape and video game/computer use in associations with PA or a health outcome, such as body mass index (BMI) (Marshall et al., 2002). Relying on a single measure of sedentary behaviour may inhibit our understanding of what young people do during their discretionary time. Further, single measures and composite variables may distort any true relationships with a dependent variable (Marshall et al., 2004). Research is therefore required to identify correlates of specific sedentary behaviours. Moreover, interventions that target a specific sedentary behaviour should assess other behaviours youth engage in, in order to establish if compensatory changes in time spent in those behaviours occurs (Robinson, 1999).

On reflection of the literature it is evident that correlates of PA in youth include behavioural, psychological and contextual variables, highlighting youth PA as a complex behaviour determined by many factors (Nigg and Paxton, 2008; Sallis et al., 2000). These findings support ecological models of behaviour that indicate personal, social and physical environmental factors influence behaviour (Sallis and Owen, 1999). The only conceptual model for the promotion of PA among youth is Welk's (1999) Youth Physical Activity Promotion Model (YPAP; Figure 1.1), which is based on an ecological framework (Green and Kreuter, 1991).

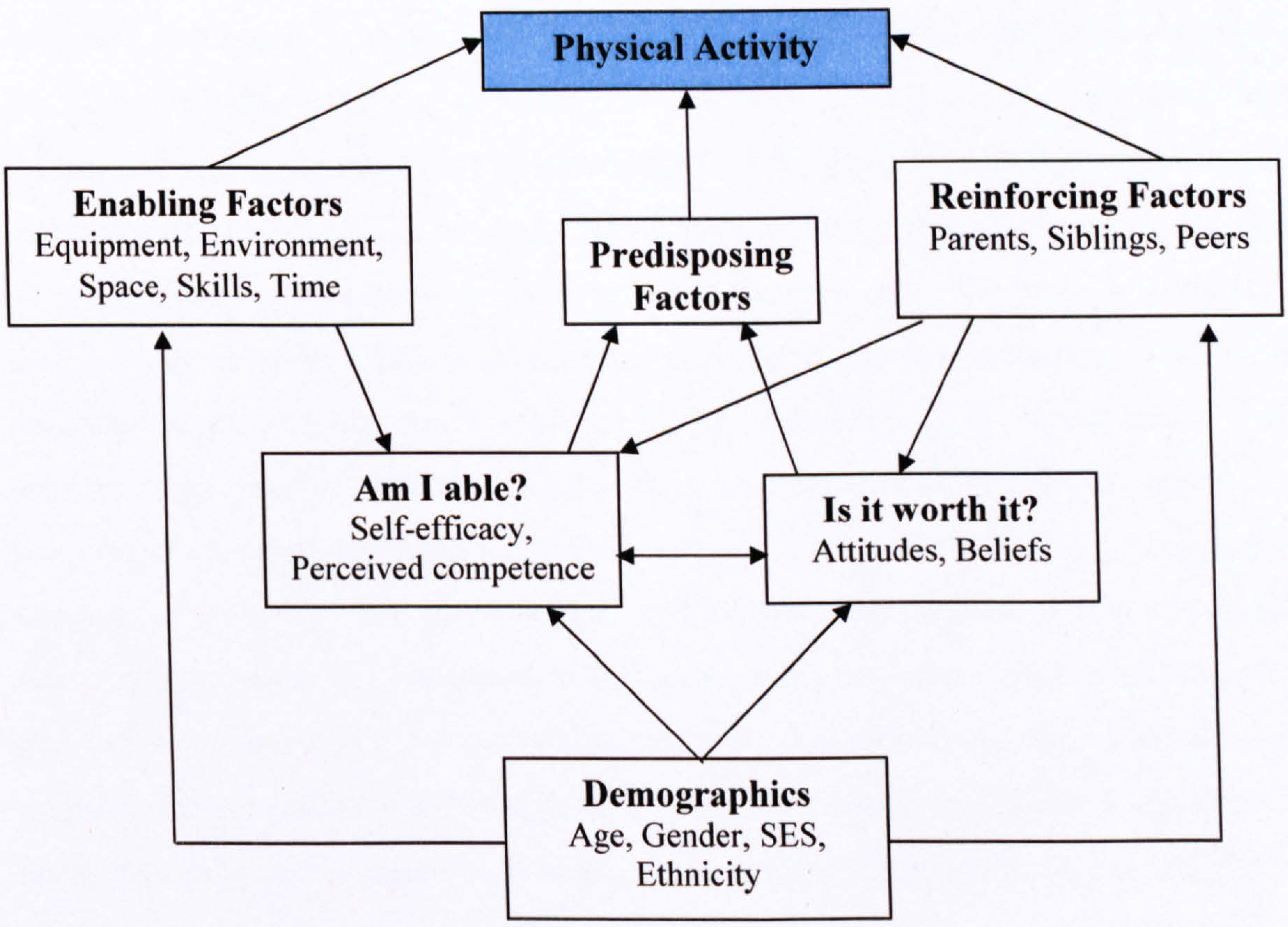

Figure 1.1 Welk's (1999) Youth Physical Activity Promotion Model (YPAP).

The YPAP model identifies and considers a population's needs and characteristics whilst acknowledging the direct and indirect behavioural influence of the environment (Welk, 1999). The model provides a bottom-up framework that includes demographic, enabling, predisposing and reinforcing factors, all deemed to influence youth PA (Welk, 1999). In the context of PA promotion through active video gaming, young people can be provided with active video gaming equipment (enabling factor) and encouraged by parents and siblings to play active rather than sedentary video games (reinforcing factor). The basic movements typically required to play active video games may increase PA self-efficacy in young people (predisposing factor). Further, reinforcement from parents can encourage young people to adopt the attitude and belief that active video gaming is worthwhile over sedentary gaming (predisposing factor). The extent to which these factors combine to influence young people's video gaming preferences and PA in the home is currently unknown and warrants attention. This thesis will focus on whether young people enjoy playing active video games (predisposing factor), create opportunities for PA in the home by providing young people with active video gaming equipment (enabling factor), and, target young people for intervention based on SES (demographic factor).

1.3 Organisation of the thesis

The main theme of this thesis is to examine the effect of active video games on PA, sedentary behaviour and health in young people. Chapter 2 provides a review of the literature. The key topics discussed are the measurement and prevalence of PA and sedentary behaviour in youth, interventions targeting increased PA and reduced sedentary behaviour in youth, and, the effects of active video games on PA, sedentary behaviour and health in youth. Through this review, highlighted limitations and gaps in the literature will provide a rationale for the three cross-sectional laboratory-based studies and one randomised controlled trial (RCT) designed for this thesis. Few studies have compared PA and EE levels in young people during sedentary and active video gaming. Chapter 3 examines this issue in adolescents. Chapter 4 presents a methodological study that uses multiple PA measurement tools to examine the contribution of different body movements to adolescents' EE during active video gaming. This study analyses whether the additional assessment of upper limb movements through accelerometry can improve EE predictions over sole activity monitoring at the hip. The physiological and enjoyment responses to a short period of active video gaming in young people and adults have not been investigated. Chapter 5 examines this issue and compares findings with those observed for sedentary video gaming and two modes of exercise. The final study, reported in Chapter 6, evaluates the short-term effect of a home-based active video gaming intervention on habitual PA and sedentary time, behaviour preferences and body composition in children. To conclude, Chapter 7 synthesises results from the four studies and their implications in relation to the major themes in the thesis. Directions for future research are also suggested.

Chapter 2

Literature Review

Literature review

2.1 Physical activity, sedentary behaviour and health

Physical activity can favourably modify health. In adults, higher levels of habitual PA are associated with reduced anxiety and depression, enhanced feelings of well-being (Kesaniemi et al., 2001), and, lower risks of health outcomes such as cardiovascular disease (Lakka et al., 1994; Blair et al., 1989; Carnethon et al., 2003; 2005), metabolic syndrome (LaMonte et al., 2005; Laaksonen et al., 2002; Ekelund et al., 2005), type 2 diabetes (Lynch et al., 1996; Hu et al., 2001; Bassuk and Manson, 2005) and all-cause mortality (Paffenbarger et al., 1986; Laukkanen et al., 2001). A dose-response relationship exists between PA and the risk of disease and all-cause mortality in adults, and moving individuals from inactive to low to moderate levels of PA will produce the greatest reductions in health risk (Kesaniemi et al., 2001; Lee and Skerrett, 2001). Promoting low to moderate levels of PA to inactive individuals is supported by research indicating that nonexercise activity thermogenesis (NEAT); the EE associated with everyday activity other than sleeping, eating and volitional exercise, is predictive of fat gain (Levine, 2007; Levine et al., 1999). In adults overfed for 8 weeks, those who increased their NEAT had a lower gain in fat mass compared to adults who did not (Levine et al., 1999). Thus, the promotion of NEAT-enhanced living is probably important for preventing health outcomes associated with fat gain (Levine, 2007), such as cardiovascular disease.

In children and adolescents, regular PA can benefit psychological health through decreased depression (North et al., 1990), and, increased self-esteem (Mutrie and Parfitt, 1998) and emotional well-being (Steptoe and Butler, 1996). When considering physiological health, risk factors for, rather than incidents of disease are related to PA in youth. This is because risk factors begin development in youth (McGill et al., 2000), while the incident of disease is more likely seen in adulthood. Cross-sectional studies on disease risk factors in youth have reported inverse relationships between habitual PA and clustering of cardiovascular disease risk factors (Andersen et al., 2006) and insulin resistance (Brage et al., 2004b; Ku et al., 2000), and, between cardiorespiratory fitness and insulin resistance (Ku et al., 2000; Imperatore et al., 2006). Higher levels of PA are therefore important from an early age. Cardiovascular disease risk factors in the study of

Andersen et al. (2006) included systolic blood pressure, triglycerides, insulin resistance, sum of four skinfolds and aerobic fitness.

Ekelund et al. (2007) found PA and cardiorespiratory fitness to be separately and independently associated with individual and clustered metabolic risk factors in a large sample of European children. For PA, associations were independent of body fat, which suggested that increased PA may benefit child health regardless of the level of adiposity. Independent associations with risk factors for PA and cardiorespiratory fitness implied favourable changes to children's metabolic risk profile can be achieved through PA that is not necessarily vigorous or exhaustive, which is necessary for the development of cardiorespiratory fitness (Baquet et al., 2003). This suggested lower intensity activities that children may be more willing to participate in can be used to increase total PA and promote metabolic and cardiovascular health (Ekelund et al., 2007). This supported the hypothesis that NEAT is pivotal in EE and weight gain regulation in children as well as adults (Levine, 2007), and is important as cardiovascular risk factors track from childhood to adulthood (Nicklas et al., 2002; Bao et al., 1994; Lambrechtsen et al., 1999).

Longitudinal studies have found weak relationships between adolescent PA and the level of cardiovascular risk factors in young adulthood (Boreham et al., 2002; Twisk et al., 2002; Hasselstrom et al., 2002; Lefevre et al., 2002). These results may be limited though due to a reliance on self-report measures of PA in these studies. In contrast, cardiorespiratory fitness in adolescence was found to strongly predict adult cardiovascular risk profile (Boreham et al., 2002; Twisk et al., 2002; Hasselstrom et al., 2002). The association with adult cardiovascular risk profile for adolescent cardiorespiratory fitness but not PA may be due to cardiorespiratory fitness being more stable in youth than PA, even when PA is objectively measured (Ekelund, 2008). Physical activity in childhood has also been reported to track into adolescence (Kristensen et al., 2008) and adulthood (Telama et al., 2005; Telama, 2009). Therefore, a physically active lifestyle in childhood is important for current health and provides a stronger platform for the maintenance of good health throughout the lifecourse.

The rising prevalence of childhood overweight and obesity in many industrialised countries is an additional concern for the current and future health of children (Reilly and Dorosty, 1999; Chinn and Rona, 2001). In Liverpool, over one-third of children aged 9 to 10 years old are classified as overweight or obese (Stratton et al., 2007). Overweight and obesity is a metabolic disorder characterised by the excess accumulation of body fat, caused primarily by an energy imbalance from increased energy consumption and reduced EE. Cross-sectional studies have reported a negative dose-response relationship between PA and childhood body fat (Ekelund et al., 2004a) and BMI (Ness et al., 2007). In a large cohort of children above the 95th percentile for BMI, 65% exhibited excess adiposity while 39% had at least two cardiovascular risk factors including adverse levels of lipids, insulin or blood pressure (Freedman et al., 2007). Furthermore, childhood overweight is strongly predictive of overweight and health problems in adulthood (Must et al., 1992; Whitaker et al., 1997; Eisenmann, 2004), indicating a need for preventive action in childhood.

To better inform preventive action it is important to understand the factors that contribute to childhood overweight. Given the human gene pool has not changed dramatically over recent decades, it has been suggested that socio-cultural and environmental factors such as greater levels of environmental risk perceived by parents, increased food availability, greater reliance on motorised transport and sedentary leisure activities are key mediators of energy imbalance (Spanier et al., 2006; Biddle et al., 1998). Of these, the effect of sedentary behaviour on obesity and health has received growing interest (Brown et al., 2008).

Objectively measured time spent sedentary has been associated with individual and clustered metabolic risk in a large sample of European youth (Ekelund et al., 2007). Reducing sedentary time seems important therefore for improving metabolic and cardiovascular health. This supports the description of sedentary behaviour as a modifiable risk factor for lifestyle related diseases (Blair and Connelly, 1996). The most common sedentary behaviours young people engage in are screen-based, and include TV, video game and computer use (Marshall et al., 2006). Television viewing has been cross-sectionally and longitudinally associated with increased body weight in youth (Ekelund et al., 2006; Hancox et al., 2004; Rey-Lopez et al., 2008). Of the theories attempting to explain this association, two have received much attention: 1) TV viewing reduces EE from a displacement of PA, and, 2) TV viewing increases energy intake during the activity or as a consequence of food advertising (Robinson, 1999).

In a recent study, Ekelund et al. (2006) examined the validity of these mechanisms in a large sample of 9 and 15 year olds. No association was found between TV viewing and the total volume of PA (CPM) as assessed by accelerometry. An association independent of PA between TV viewing and skinfold-measured adiposity was reported however, and TV viewing was associated with the frequency of eating meals while watching TV (Ekelund et al., 2006). Increased energy intake has similarly been associated with TV viewing in non-overweight children (Epstein et al., 2005). Contrary to the first mechanism therefore, Ekelund et al. (2006) supported the suggestion of Marshall et al. (2002) that TV viewing does not displace PA and can coexist with an active lifestyle, with increased energy intake during or as a consequence of TV viewing the seemingly more important mechanism influencing energy imbalance. It is important to note that this conclusion is only applicable to total PA and TV viewing may relate differently to time spent sedentary or in different intensities of activity. Research suggests that TV viewing may reduce participation in vigorous (Marshall et al., 2004) or low intensity activities (Robinson, 2001; Lowry et al., 2002). Assessing subcomponents of PA, in experimental trials aimed to reduce screen time for example, would more definitively assess specific mechanisms that account for changes in adiposity (Robinson, 1999). The study of Ekelund et al. (2006) was also limited by participants self-reporting time spent watching TV only before and after school. Media use is reportedly greater on non-school days in youth (Olds et al., 2006), therefore failure to assess weekend TV viewing was the likely reason for the low sample mean for TV use, with such underestimation potentially obscuring an inverse relationship with PA (Prentice and Jebb, 2006).

In contrast to TV viewing, weaker associations have been found between obesity and video game and computer use in children and adolescents (Burke et al., 2006; Rey-Lopez et al., 2008). Moreover, while cross-sectional studies have found positive associations between obesity and video game (Stettler et al., 2004; Vandewater et al., 2004; Laurson et al., 2008) and computer use (Wardle et al., 2001; Kautiainen et al., 2005), longitudinal studies have found no relationship between video game/computer use and weight gain (Gordon-Larsen et al., 2002; Janz et al., 2005). Weaker associations between obesity and video game/computer use compared to TV viewing are likely due to young people devoting more time to TV viewing (Rey-Lopez et al., 2008).

Furthermore, compared to seated rest, video gaming elicits greater EE (Maddison et al., 2007) and presents a reduced opportunity for energy intake, as it is typically necessary to hold a video game controller with both hands (Rey-Lopez et al., 2008).

The energy cost disparity between video gaming and seated rest has led to the suggestion that replacing TV viewing with sedentary video gaming may positively affect EE, if all other factors such as energy intake and habitual PA remained constant (Wang and Perry, 2006). This though is unlikely to have similar benefits to if PA replaced TV viewing. However, advancements in video game technology now allow young people to play active video games that incorporate PA into video gaming. Active video gaming is achieved through peripheral devices such as dance mats or the game itself, with the latter often referred to as an exergame. It could be suggested therefore that replacing TV viewing with active video gaming will positively affect EE to a greater extent than sedentary video gaming. This is supported by research indicating that young people expend significantly more energy during active than sedentary video gaming (Lanningham-Foster et al., 2006; Maddison et al., 2007). Moreover, reduced snacking has been observed in young people during active rather than sedentary video gaming (Bloom et al., 2008), which could further discourage energy intake during screen time. Replacing sedentary video gaming and TV viewing with active screen time may also benefit mental health, as psychological well-being has been negatively associated with TV, computer and video game use in children (Hamer et al., 2009) and adolescents (Ussher et al., 2007; Mathers et al., 2009).

Research investigating whether physical and mental health can be improved by converting screen time from sedentary to active is scarce. This research is necessary as 7 to 12 year old boys and girls spending over 2 $h \cdot d^{-1}$ watching TV and playing video games are reported to be 1.69 (95% confidence interval (CI): 0.90 to 3.17) and 1.22 (95% CI: 0.77 to 1.94) times more likely to be overweight than those spending less than 2 $h \cdot d^{-1}$ watching TV and playing video games, respectively (Laurson et al., 2008). Similar odds ratios for overweight of 1.63 (95% CI: 1.05 to 2.5) have been observed in Australian children aged 5 to 12 years (Spinks et al., 2007). Moreover, high media use in childhood is linked to high use in older age (Marshall et al., 2006), and, sedentary behaviours including TV and video game use track at moderate levels during childhood (Janz et al., 2005) and from childhood to adolescence (Pate et al., 1999). Thus, if active video games accrue health benefits and track as well as sedentary equivalents, they could provide a promising alternative to sedentary screen-based behaviours in the home. If combined with PA away from the screen, this could create a balanced and varied programme of regular activity for young people to participate in. Despite the acknowledged need to investigate the impact of active video games on physiological and psychological health, this thesis will only seek to investigate the former.

2.2 Measurement issues in physical activity

Sedentary behaviour and PA are important health-related behaviours; as such their assessment has become an important area of research (Fox and Riddoch, 2000). In the United Kingdom (UK) surveys are used to assess child and adolescent PA levels on a national scale. Subjective methods such as self-report questionnaires have provided information on the context of PA and sedentary behaviour, and a participant's subjective perception of these behaviours (Reilly et al., 2008). However, subjective methods have limited validity due to biased paternal reporting of their child's activity and poor child recall of previous activity (Kohl et al., 2000; Welk, 2002). Biased reporting is particularly likely from children or their parents participating in interventions aimed at behaviour change, where they favourably report the child's lifestyle (Caballero et al., 2003). Consequently, use of objective assessment tools to quantify PA and sedentary behaviour is recommended (Reilly et al., 2008).

There are over thirty methods available for measuring PA, including pedometers, heart rate (HR) monitors and accelerometers (Welk, 2002). Of these, small and unobtrusive accelerometers have become the most widely used objective assessment tool in youth (Rowlands, 2007). Accelerometers measure accelerations produced by body movements and have been reported to provide accurate and reliable information on the volume and intensity of habitual PA and the volume of sedentary behaviour in children and adolescents (Ward et al., 2005; Rowlands, 2007). Accelerometry has improved our understanding of the relationship between PA, sedentary behaviour and health outcomes in young people, and allowed investigation of dose-response relationships between PA and health (Ness et al., 2007). However, accelerometers are typically worn on the hip and are not waterproof, therefore they cannot detect PA and EE associated with carrying a load, cycling, or upper limb movement, or be worn during water-based activities including swimming (Rowlands, 2007). Activity output from uniaxial accelerometers has also been reported to plateau at running speeds of approximately 9 $km \cdot h^{-1}$ in children, largely due to the constancy of body acceleration in the vertical plane at fast speeds (Brage et al., 2003). This limitation however will only impact studies seeking to differentiate between time spent in vigorous and very vigorous intensity PA, with such activity intensities previously related to cardiorespiratory fitness (Baquet et al., 2003) and bone mineral accrual (McWhannell et al., 2008).

One of the most important limitations related to accelerometry is the disparity between data interpretation methods across research groups. Accelerometers are typically validated against indirect calorimetry and calibrated in terms of resting METs to classify the intensity of an activity (Puyau et al., 2002). One MET equates to resting energy expenditure (REE), and adult MET thresholds for light (<3 METs), moderate (3 to 6 METs), vigorous (6 to 9 METs) and very vigorous (>9 METs) activity (Freedson et al., 1998) have been applied in children and adolescents (Mattocks et al., 2007). Energy costs of 4 METs in children walking briskly, an activity deemed moderately intense (Saris, 1996), suggest this may be a more appropriate cut-point (Treuth et al., 2004; Harrel et al., 2005; Mattocks et al., 2007). Moderate intensity PA corresponds to approximately 40 to 60% of maximal oxygen consumption ($\dot{V}O_{2max}$) (Pate et al., 1998).

Calibration studies have used laboratory and field-based protocols inclusive of recreational activities typical in youth, and, treadmill or overground walking and running, to reflect that young people spend a lot of time in ambulatory activity (Eston et al., 1998; Puyau et al., 2002; Bailey et al., 1995). However, discrepancies between studies in terms of procedure, instrumentation and participants have resulted in a range of activity count thresholds being generated for MET thresholds and for the threshold between sedentary and light activity (Guinhouya et al., 2006; Rowlands, 2007). For example, moderate intensity cut points range from approximately 1000 to 3200 CPM (Trost et al., 2002; Puyau et al., 2002). Thresholds differentiating sedentary and light activity range from 100 to 800 CPM (Treuth et al., 2004; Puyau et al., 2002). This range of thresholds has led to discrepancies in the number of children and adolescents classified as sufficiently active or the time spent in sedentary behaviour (Mota et al., 2007; Reilly et al., 2008), providing mixed messages on the current activity levels of youth. The range of thresholds has also made between-study comparisons in the literature difficult, and influenced understanding of the dose response relationship between PA and health outcomes, as well as the effectiveness of interventions (Corder et al., 2007a; Jago et al., 2007). Though leading researchers have expressed their concern due to the wide use of accelerometry in children and adolescents (Ekelund et al., 2004b), no consensus exists on how to tackle this issue.

To aid comparisons across studies, a move away from the use of arbitrary count-based cut points towards an approach that summarises accelerometer data using acceleration ($m{\cdot}s^{-2}$) has been recommended (Corder et al., 2008). It may also be appropriate to modify previous calibration approaches in recognition of their limitations. Accelerometer counts are typically anchored to reference activities of walking and running, as they are the dominant activities of daily living (Bailey et al., 1995). However, large individual differences in counts have been reported in adolescents walking at 4 $km{\cdot}h^{-1}$ (400 to 2600 CPM) and 6 $km{\cdot}h^{-1}$ (1000 to 5000 CPM) (Ekelund et al., 2003), and in children during catching and hopscotch (Eston et al., 1998). Variables influencing counts generated at different ambulatory speeds include leg length, stride length and cadence (Jago et al., 2007). To account for these individual differences in biomechanical efficiency, Ekelund et al. (2003) applied individually calibrated activity count thresholds at 4 $km{\cdot}h^{-1}$ and 6 $km{\cdot}h^{-1}$ to habitual PA data. To do this, mean activity counts (CPM) for each participant at each speed were calculated over the final 2 min of a 5-min walking protocol, from an accelerometer set to record in 15-s time intervals (epochs). Each participant's total activity count per day was then divided by their CPM for each reference activity (i.e. 4 $km{\cdot}h^{-1}$ and 6 $km{\cdot}h^{-1}$ on a treadmill) and this provided an index of the time spent in minutes per day in PA equivalent to that of the reference exercises (Ekelund et al., 2003). From free-living assessments of PA the approach was reported to be significantly related to an index of the time spent at an EE equivalent to that of the same references exercises (Ekelund et al., 2003). Though the absolute time spent in PA was significantly lower for the activity count compared to EE index, this was attributed to the inability of hip-mounted accelerometers to detect the wide range of body movements in free-living, and the approach was concluded to be a valid indicator of free-living PA (Ekelund et al., 2003). A limitation of this individual calibration approach is the difficulty in applying it to large samples and the need to repeat the procedure at each assessment period in a repeated measures study due to child growth likely influencing counts generated (Jago et al., 2007). However, to improve our understanding of the prevalence of PA and sedentary behaviour and their relationship with health, to reduce measurement error which will help detect differences between groups in PA intervention studies, and, to attain congruency and advance the paediatric literature, individualised approaches to PA measurement appear necessary.

An alternative approach to improving predictions of PA and EE in youth may be to combine data from different measurement tools. Combinations that have received interest include simultaneous HR recording and movement sensing via accelerometry, and movement sensing via accelerometry at more than one body location (multi-site), for example at the hip and wrist. The rationale for combined HR and movement sensing is that limitations of the individual methods are uncorrelated (Brage et al., 2004a), whereas the use of multiple accelerometers allows PA of the upper limbs to be captured, which is not possible with hip-mounted accelerometry alone (Trost et al., 2005). Hip-mounted accelerometers measure vertical acceleration at the hip, which for the purpose of this thesis will be defined as total body movement (minus the arms).

Laboratory-based research in adults performing activities of daily living in a whole-body calorimeter (Rennie et al., 2000; Brage et al., 2004a), and in children performing treadmill walking and running (Corder et al., 2005) and activities of daily living in open areas (Corder et al., 2007b), found that combined HR and activity monitoring provided the highest correlation with EE measured by indirect calorimetry compared to either method used in isolation. Further assessment of the predictive ability of this approach in children during free-living and other childhood activities is needed however (Corder et al., 2007b).

With regard to multi-site movement sensing, research is currently limited to adults. In seventy, 19 to 74 year old adults performing six activities of daily living, such as yardwork, housework, family care and walking, Swartz et al. (2000) compared EE assessed by indirect calorimetry to EE estimates derived from three site-specific prediction equations that converted accelerometer activity counts to METs. Equations used counts from an accelerometer placed on the right hip, dominant wrist, or a combination of counts from the hip and wrist. Regression analyses indicated the combined hip and wrist equation (34.3%) accounted for significantly more variation in EE than the hip (31.7%) or wrist (3.3%) equation alone. Despite hip activity data only accounting for a third of the variance in EE, the 2.6% increase in explanatory power from the wrist accelerometer was concluded insufficient to warrant the associated cost of the additional monitor and time required to analyse the data (Swartz et al., 2000). This was supported by Kumahara et al. (2004) who observed in eighty-eight, 18 to 64 year old adults spending 24 h in a large respiratory chamber, that the addition of accelerometer counts from the dominant wrist to that of the waist improved the prediction of daytime EE by only 1.5%. These findings are also congruent with those of Melanson and Freedson (1995). Despite prediction equations using counts from accelerometers placed at two (ankle and hip, hip and wrist) and three (ankle, hip and wrist) sites providing more precise estimates of EE than single sites during treadmill walking and jogging in adults, the improvements were not deemed significant (Melanson and Freedson, 1995). Consequently, these studies offered little support for the use of multiple accelerometers to predict PA and EE.

To date, no published study has investigated the use of multiple accelerometers to predict PA and EE in young people, which has been described as an oversight in the literature and an area for future research (Trost et al., 2005). Assessment of upper limb movements is warranted in youth, as young people are more likely to engage in activities that involve use of the arms, such as playing with toys or a musical instrument, playing racket or ball sports, skipping, and other playground games (Eston et al., 1998; Vandewater et al., 2006). Upper limb movements have also been reported to provide a substantial contribution to the total PA of daily living in adults (Kumahara et al., 2004). Therefore, it is likely that through typical childhood activities this contribution will be greater in youth, supporting the need to examine if the assessment of upper limb movements in addition to total body movements will improve predictions of EE (Trost et al., 2005).

2.3 Physical activity and sedentary behaviour: guidelines for youth

Accurately measuring PA is important for determining whether young people are sufficiently active to meet health-benefitting PA guidelines. Currently, children and adolescents aged 5 to 18 years are recommended to perform a total of at least 60 $min \cdot d^{-1}$ of MVPA (Biddle et al., 1998; DH, 2004). Activities to improve bone health, muscle strength and flexibility should be included in this at least twice a week (Biddle et al., 1998; DH, 2004). Achievement of these guidelines should occur through activities that are developmentally appropriate from a physiological and behavioural perspective (Biddle et al., 1998). For example, adolescents may be more likely to engage in structured continuous bouts of MVPA and children intermittent bouts of activity throughout the day (Biddle et al., 1998). These guidelines were based on descriptive data indicating that despite most children achieving the adult recommendation of 30 $min \cdot d^{-1}$ of moderate activity (Pate et al., 1994; Cale and Almond, 1997), many exhibited modifiable risk factors for cardiovascular disease (Baranowski et al., 1992) and the prevalence of obesity was still rising (Hughes et al., 1997), hence the need for more activity.

The authors acknowledged that these recommendations were limited, as they were not based on compelling epidemiological or experimental evidence (Biddle et al., 1998). This view has since been reiterated, with concern that 60 $min \cdot d^{-1}$ may be insufficient to maintain a favourable metabolic profile (Boreham and Riddoch, 2001; Twisk, 2001). In a recent study, Andersen et al. (2006) observed a graded negative association between clustered cardiovascular disease risk and PA measured by accelerometry in 9 and 15 year old children. Compared to the most active quintile, risk was raised from PA quintiles one to three, and 9 and 15 year old children in the fourth quintile participated in 116 and 88 $min \cdot d^{-1}$ of moderate intensity PA, respectively (Andersen et al., 2006). This confirmed previous views and the authors concluded that current guidelines underestimated the PA required to prevent clustering of risk factors in youth, with 90 $min \cdot d^{-1}$ recommended as necessary (Andersen et al., 2006). However, this figure is anchored to levels of activity observed in 15 year old adolescents, and participation in 120 $min \cdot d^{-1}$ of at least moderate intensity PA should be recommended to children aged 9 years.

In contrast to PA, few published reports present guidelines for the amount of time young people should spend sedentary each day (Marshall and Welk, 2008). This is despite strong consensus among experts that young people should completely avoid prolonged periods of inactivity (Corbin and Pangrazi, 2004). The formation of evidence-based sedentary guidelines have been inhibited by uncertainty over what a prolonged period of inactivity constitutes (Marshall and Welk, 2008), and, a paucity of secular data on sedentary behaviours and their relationship with health (Biddle et al., 2004b). Further, though sedentary behaviours such as reading and talking with friends may not be deemed physiologically beneficial, as they elicit a low EE, they are important for healthy social and cognitive development (Marshall and Welk, 2008). To date therefore, sedentary guidelines have focused on the time young people should spend engaged with screen-based media.

The American Academy of Pediatrics (AAP; 2001) recommended that paediatricians advise parents to limit children's total time with entertainment media, which included TV and videotape use, to 2 $h \cdot d^{-1}$ of quality programming, and completely discourage TV viewing in children younger than 2 years. Quality programming should be informational, educational and nonviolent (AAP, 2001). This guideline was based on research reporting negative health effects of TV viewing on outcomes including violence and aggressive behaviour, academic performance, body concept and self image, nutrition, dieting and obesity (AAP, 2001). Media use was assumed to interfere with time spent in more active and meaningful pursuits, such as reading, socialising with friends and parents or exercising (AAP, 2001), a view echoed by the Centres for Disease Control and Prevention (2006). However, as discussed TV viewing is likely to impact obesity through increased energy intake rather than the displacement of PA.

Beyond the AAP recommendations, only Australia and Canada have formally published sedentary guidelines. The Australian Government (2005) extended the AAP recommendation, advising that children spend less than 2 $h \cdot d^{-1}$ using electronic media for entertainment, inclusive of computer games, internet, and TV, particularly during daylight hours. Health Canada (2002) recommended that physically inactive children spend at least 30 min less each day viewing TV, playing computer games and surfing the internet. Further, over several months young people should decrease the time spent on inactive pursuits such as watching videos and using a computer, by at least 90 $min \cdot d^{-1}$. Though these guidelines fail to differentiate between active and sedentary modes of screen-based media, their existence highlights that PA and sedentary behaviour may carry independent health risks, high volumes of each can coexist within the lifestyle of a young person, and, these behaviours can be targeted independently (Marshall et al., 2002; Marshall and Welk, 2008).

2.4 Physical activity and sedentary behaviour: patterns and prevalence in youth

Children's activity patterns are influenced by an inherent desire to explore and an inability to delay gratification (Marshall and Welk, 2008). Consequently, compared to adults who tend to engage in sustained bouts of PA, research using direct observation (Bailey et al., 1995) and accelerometry (Baquet et al., 2007) has found children's activity to consist of short bursts of high intensity activity interspersed with low to moderate intensity activity of varying duration. Approximately 95% of children's high intensity bouts lasted less than 15 s (Bailey et al., 1995) or 10 s (Baquet et al., 2007) with a mean duration of 3 s in both studies. The mean duration of light and moderate intensity bouts was 6 s (Bailey et al., 1995) and 9 s (Baquet et al., 2007). This spontaneous, intermittent activity pattern indicates that children will tend to accumulate PA in short bursts throughout the day (Welk et al., 2000). Thus, to more accurately assess children's habitual PA, high (5 to 10 s) rather than low frequency (60 s) accelerometry monitoring is advised (Rowlands, 2007).

A large number of studies have used accelerometry to investigate the public perception that PA in children and adolescents has declined over recent years with many failing to comply with current guidelines (Biddle et al., 2004b). Evidence to date though does not allow confident conclusions surrounding these issues to be made. First, there is a lack of quality secular trend data for accelerometer-assessed PA. Secondly, available trend and cross-sectional data is difficult to interpret and compare due to the predominant use of 60-s epochs (i.e. low frequency accelerometry) and the discrepancy between activity count thresholds for moderate intensity activity.

Between studies using 60-s epochs, large differences are evident in the time young people reportedly spend in moderate PA or MVPA. This is due to the use of different thresholds to define moderate PA. In the literature there are arguably three bands within which moderate intensity activity counts for youth have fallen. First, the Freedson et al. (1997) age-specific equation has been used to generate relatively low count thresholds for moderate activity of 802, 906, 1017 and 1600 CPM in 8, 9, 10 and 15 year olds, respectively (Trost et al., 2002; Pate et al., 2002; Riddoch et al., 2004; Nadar et al., 2008). Møller et al. (2009) adopted this approach in 8 to 10 year olds, but used a threshold of 1000 CPM for moderate activity by rounding to the nearest hundred counts, assumingly based on the mean sample age approximating 9.7 years. The Freedson et al. (1997) equation was generated from accelerometer (Computer Science and Applications, model 7164, ActiGraph Ltd, Pensacola, FL, USA) activity counts calibrated against respiratory gas analysis in fifty children aged 6 to 17 years performing two 5-min walking protocols and one 5-min jogging protocol on a motorised treadmill. Cross-validation of the equation in thirty similarly aged participants revealed no difference between actual and predicted EE ($r = 0.86$) (Freedson et al., 1997). Studies utilising the equation have reported a high prevalence of MVPA in 9 to 11 year old children, from 120 to 192 $min \cdot d^{-1}$ in boys and 100 to 160 $min \cdot d^{-1}$ in girls (Trost et al., 2002; Pate et al., 2002; Riddoch et al., 2004; Nadar et al., 2008; Moller et al., 2009). The prevalence of MVPA in 15 year old boys ranged between 55 and 99 $min \cdot d^{-1}$, and in girls between 36 and 73 $min \cdot d^{-1}$ (Trost et al., 2002; Pate et al., 2002; Riddoch et al., 2004; Nadar et al., 2008). The majority of children and adolescents in these studies were subsequently concluded as sufficiently active based on the current PA guideline.

Conversely, the European Youth Heart Study group have used a higher threshold of 2000 CPM for moderate activity in 9 and 15 year olds (Andersen et al., 2006; Ekelund et al., 2007; Nilsson et al., 2009). This was based on validation studies that purportedly indicated similar counts in children exercising at 3 METs during treadmill or overground walking at 4 $km \cdot h^{-1}$ (Trost et al., 1998; Puyau et al., 2002; Brage et al., 2003; Ekelund et al., 2003; Treuth et al., 2004). This cut point may be too low and overestimate moderate activity however, as studies in which children and adolescents walked at 4 $km \cdot h^{-1}$ reported mean activity counts of 2381 CPM (Brage et al., 2003), 2356 CPM (Treuth et al., 2004) and 2471 CPM (Puyau et al. 2002). Mean counts of 2500 CPM were similarly reported by Metcalf et al. (2008) in prepubertal children walking at 4 $km \cdot h^{-1}$. From the data of Nilsson et al. (2009) the weighted week mean for MVPA in youth from four European countries was calculated, which in 9 year old boys and girls was 97 and 70 $min \cdot d^{-1}$, respectively, and in 15 year old boys and girls 74 and 55 $min \cdot d^{-1}$, respectively. Metcalf et al. (2008) reported 57 (boys) and 45 (girls) $min \cdot d^{-1}$ of MVPA in 8 year old British children. Compared to studies that used the Freedson equation therefore, a larger proportion of youth and especially 9 year old children in these samples were deemed insufficiently active to benefit health.

In contrast to both these approaches, studies using high thresholds of 3600 CPM (Riddoch et al., 2007) and 3200 CPM (McLure et al., 2009) for moderate activity concluded almost all girls and boys aged 9 to 11 years to fall short of the current PA guideline, supposedly achieving only 16 to 29 $min \cdot d^{-1}$ of MVPA. The 3600 CPM threshold was established from children walking on a treadmill at a moderate intensity of 4 METs (Riddoch et al., 2007). This threshold fell between a comfortable (4.4 $km \cdot h^{-1}$; 2950 CPM) and brisk (5.8 $km \cdot h^{-1}$; 4175 CPM) walking speed (Riddoch et al., 2007). The 3200 CPM threshold was derived from a prediction equation that regressed EE against counts generated by children performing a range of structured activities in a whole room calorimeter (Puyau et al., 2002). It is clearly evident therefore that when assessing habitual PA in 60 s epochs, the number of children and adolescents deemed sufficiently active will depend on the count threshold selected for moderate intensity activity and this makes comparability between studies difficult.

While the debate will continue regarding which threshold for moderate intensity PA is most suitable, the variability reported across groups in MVPA would likely be minimised if PA was monitored in 5-s rather than 60-s epochs, and the 60-s count threshold was converted into a 5-s threshold. This is because a 60-s epoch sums all the counts over a minute, and compares this value to the CPM threshold. Thus, if a child performed 15 s of high intensity activity and then rested for 45 s, the sum of counts would likely be greater than a low threshold for moderate PA (e.g. Freedson 906 CPM) but lower than a high threshold (e.g. Riddoch 3600 CPM). Consequently, the child would be classified as engaging in 60 s (Freedson) or 0 s (Riddoch) of moderate PA, respectively. If though, the 60-s threshold was converted to a 5-s count per epoch (CPE) threshold, by dividing by twelve, then regardless of the original CPM threshold a more accurate estimation of MVPA would be likely, i.e. 0 to 15 s rather than 0 to 60 s, and, the discussed discrepancies between studies minimised. High frequency monitoring is supported by research indicating that 60-s epochs underestimate moderate and vigorous intensity PA in children compared to a 5-s epoch, when a moderate threshold of 1956 CPM (Nilsson et al., 2002) and 1952 CPM is used (Corder et al., 2007c).

Despite this methodological issue, the aforementioned studies confirmed important conclusions from recent reviews (Biddle et al., 2004b; Strong et al., 2005). Boys are more active than girls across childhood and adolescence, especially at a high intensity, and an age-related decline in activity across adolescence is evident. Relatively stable PA levels in children tracked annually from 5 to 8 years of age (Metcalf et al., 2008) further suggests PA promotion is vital in children, and especially girls, as they move into the pubertal transition (about age 10 to 14 years) (Strong et al., 2005). Early intervention is supported by self-report (Brodersen et al., 2007) and accelerometry-based research indicating sedentary time to be greater in adolescents than children (Ekelund et al., 2007; Van Sluijs et al., 2008; Nilsson et al., 2009), and, in girls than boys throughout childhood and adolescence (Ekelund et al., 2007; Riddoch et al., 2007). These findings were consistent despite a range of thresholds being used to define sedentary time ($\leq$ 100 to 500 CPM) (Nilsson et al., 2009; Riddoch et al., 2007; Van Sluijs et al., 2008; Ekelund et al., 2007). Activity counts of approximately 100 CPM have been observed in children sitting (Puyau et al., 2002), suggesting a relatively low threshold will avoid including time spent in very light to light intensity activity (Van Sluijs et al., 2008). Thus, accelerometry-assessed sedentary time will be defined as $\leq$ 100 CPM in this thesis.

Total activity (CPM) and time spent in MVPA were reportedly greater on weekdays than weekend days (Riddoch et al., 2007; McLure et al., 2009; Nilsson et al., 2009). This is congruent with previous findings in adolescents (Trost et al., 2000; Treuth et al., 2007) and children (Rowlands et al., 2008). However, between-day variability was found to depend on geographical location (Nilsson et al., 2009), gender (Nadar et al., 2008), and age, with children reported to be more active on weekend days (Trost et al., 2000). The difference in findings may be due to the use of different PA assessment methods and thresholds to define moderate intensity activity (Nilsson et al., 2009). Nilsson et al. (2009) also found time spent sedentary to be greater in 9 and 15 year olds on weekdays compared to weekend days, supporting suggestions that a high volume sedentary time is not necessarily accompanied by low levels of PA.

Nilsson et al. (2009) presented novel results on the variability in PA between school and leisure time in children and adolescents. Though differences in the average level of PA between school and leisure time were inconsistent across four European countries, MVPA was typically similar or greater during school compared to leisure time (Nilsson et al., 2009). This may be due to PA opportunities during recess (Ridgers et al., 2006) and physical education (PE) lessons (McKenzie et al., 1996). A low proportion of children and adolescents failed to accumulate 60 min of MVPA during school, leading to the suggestion that increasing opportunities for PA during leisure time is important to support more children to meet current PA recommendations (Nilsson et al., 2009). This is especially important from a young age, as sedentary time was predominantly greater in 9 year olds during leisure time than at school (Nilsson et al., 2009).

The increased time young people spend sedentary out of school should be expected, as young people in affluent countries spend more time engaged in screen-based activities than any other activity besides sleep (Woodward and Gridina, 2000; Roberts and Foehr, 2004; Marshall et al., 2006). Young people watch TV for 2 to 4 $h \cdot d^{-1}$ (Olds et al., 2006; Gorely et al., 2004; Laurson et al., 2008), and use video games and computers for 30 to 45 $min \cdot d^{-1}$ each (Woodward and Gridina, 2000; Marshall et al., 2006), though 75% of UK youth were found to play video games for 6 to 14 $h \cdot wk^{-1}$ (Pratchett, 2005). Television viewing and computer use are reportedly consistent between genders (Marshall et al., 2006; Laurson et al., 2008), though in a large sample of Liverpool children aged 9 to 10 years, boys' TV and video game use was greater than girls (Fairclough et al., 2009). Greater video game use in boys than girls have previously been reported (Marshall et al., 2006; Olds et al., 2006; Cummings and Vandewater, 2007; Laurson et al., 2008). Boys may spend more time compared to girls watching TV and playing video games due to girls devoting more time to activities such as talking on the phone, doing homework or reading (Hager, 2006). Though age-related trend data for video game and computer use is lacking (Marshall et al., 2006), TV viewing is thought to increase from 6 to 11 years of age, peak between the ages of 9 and 13 years, and decline through adolescence (Rosengren and Windahl, 1989; Gorely et al., 2004; Marshall et al., 2006). In contrast to objectively measured sedentary time (Nilsson et al., 2009), research suggests engagement with screen-based media is greater on weekend compared to weekdays (Olds et al., 2006; Cummings and Vandewater, 2007). This may be due to young people having more free time at the weekend and spending prolonged periods sedentary in lessons at school on weekdays.

The time spent watching TV and playing video games on weekday and weekend days in Liverpool children is inversely associated with SES (Fairclough et al., 2009). This is congruent with previous research (Gorely et al., 2004; Jago et al., 2008) and supports the suggestion that socio-demographic factors such as maternal education, family income and SES have a stronger relationship with sedentary behaviours than psychosocial and behavioural factors including school PE participation and use of community recreation centres (Gordon-Larsen et al., 2000). Several factors are suggested to contribute to the association between SES and time spent in sedentary behaviours. Despite their potential high cost, parents may encourage children to engage in sedentary screen-based activities in the home over PA outside due to a poor perception of environmental safety in low SES communities (Goodway and Smith, 2005; Farley et al., 2007). Occupying a child with screen-based entertainment may also appeal to low income or single parent families (Hesketh et al., 2006), as it requires low parental input and presents a cheaper option to other leisure activities (Larson and Verma, 1999; McElroy, 2008). Moreover, children to parents of high income or educational level may be better encouraged and supported to participate in PA (Stenhammer et al., 2007), as a result of fewer financial restraints and a greater understanding of the health benefits of PA in parents (Saelens and Kerr, 2008). This has led to suggestions that intervention is required to address such inequalities in the prevalence of sedentary behaviour and PA participation (Fairclough et al., 2009). This is especially warranted as 27% of boys and 35% of girls reportedly exceed the 2 $h \cdot d^{-1}$ screen time recommendation (Laurson et al., 2008), and 30% of boys and 25% of girls are high TV users (> 4 $h \cdot d^{-1}$) (Marshall et al., 2006).

Though prevalence data indicates that insidiously attractive screen-based media are dominant leisure pursuits for contemporary youth (Pate, 2008), available secular data suggests this prevalence has not changed dramatically over recent decades. Eleven to 17 year olds in the 1960s and 1970s watched TV for approximately 3.1 $h \cdot d^{-1}$ (Schramm et al., 1961; Greenberg, 1976) and spent approximately 36 $h \cdot wk^{-1}$ outside of school engaged with mass media including TV, radio, vinyl records and comic books (Schramm et al., 1961), which are consistent with current estimates. Thus, Biddle et al. (2004b) suggested that while the content of media has changed, the volume has not, and may represent a maximum time young people can devote to it. This would support suggestions that while the large amount of time young people spend engaged with screen-based media is inevitably prohibitive of PA and a contributor to a sedentary lifestyle (Biddle et al., 2003), media use may be unfairly implicated in the displacement of PA (Biddle et al., 2004b; Marshall et al., 2004), with energy intake the more important mechanism contributing to childhood overweight and obesity (Robinson, 1999). Increasing PA and reducing screen time related energy intake therefore seems important for the promotion of an active, healthy lifestyle, especially in children from lower SES groups.

2.5 Physical activity and sedentary behaviour interventions in youth

Increasing opportunities for PA is considered an essential option for dealing with the rising incidence of obesity and to support more young people to meet PA recommendations (National Institute for Clinical Excellence (NICE), 2006; Mohebati et al., 2007; Nilsson et al., 2009). This is supported by Welk's (1999) ecological approach for behaviour change, the YPAP model, which states that enabling factors such as equipment, space, time availability and suitable facilities will allow children to be physically active. In this model, enabling factors reside within a conceptual framework including demographic, predisposing and reinforcing factors, all deemed to influence youth PA (Welk, 1999). Unmodifiable demographic factors of a population such as age, gender, ethnicity and SES influence the likelihood of a child engaging in PA, specifically the child's predisposition of their ability to be physically active and whether participation is worthwhile; the significant others that can reinforce PA, namely parents and peers; and the aforementioned environmental determinants that allow children to be active (Welk, 1999). Based on the Precede-Proceed model (Green and Kreuter, 1991) and social ecological framework (McLeroy et al., 1988), which identified and considered a populations needs and characteristics whilst acknowledging the direct and indirect behavioural influence of the environment (Welk, 1999), the YPAP model has been used to guide school-based PA interventions (Stratton, 2000; Stratton and Mullan, 2005; Ridgers et al., 2007) despite no published validation of the model (Rowe et al., 2003).

School-based interventions promoting PA through the provision of enabling and reinforcing factors are recommended, as children spend a large portion of their day in school and this setting can play an important role in the development of PA and health behaviours (Kohl and Hobbs, 1998; Stokols et al., 2003). Interventions that have adapted the PE curriculum (Almond and Harris, 1998; Stone et al., 1998; Mallam et al., 2003) and introduced playground markings and physical structures (Stratton, 2000; Stratton and Mullan, 2005; Ridgers et al., 2007) have increased children's PA during PE and recess. However, increased PA outside of school and benefits to body composition, as measured by BMI, are rarely observed (Harris et al., 2009). A year-long intervention of biweekly after-school high intensity PA or fundamental movement skill clubs similarly did not improve accelerometry-assessed habitual PA or dual-energy x-ray absorptiometry (DXA) assessed body fat in 9 to 10 year old children compared to controls receiving no intervention at 9 and 12 months from baseline (Ridgers et al., unpublished data). The failure of these school-based interventions to promote habitual PA is unsurprising however; as they did not include family or community support that encourages the maintenance of behaviour change (Eisenmann et al., 2008).

One of the few multi-level interventions that included a family component to reinforce a school-based intervention was the Child and Adolescent Trial for Cardiovascular Health (CATCH; Edmundson et al., 1996). This intervention was found to improve knowledge and self-efficacy for healthy food choices and PA in young people (Edmundson et al., 1996). However, self-reported changes in PA beyond the school-based intervention alone were not observed, and this was attributed to the low intensity of the home-based component (Nader et al., 1996). A dose-response effect was observed however, with families that demonstrated greater parental involvement having greater acquisition of knowledge and attitudes towards health habit changes, which supports the positive influence of the family on psychosocial determinants (Nader et al., 1996). Support for family and community involvement is also evident from the APPLE project, which employed community activity coordinators to maximise opportunities for PA during extra-curricular time at school and during leisure time in primary school children aged 5 to 12 years (Taylor et al., 2006). After 1-year, intervention children spent less time sedentary, more time in MVPA and exhibited a lower change in BMI z-score compared to controls (Taylor et al., 2006). Conclusions based on the accelerometer-assessed PA data are limited however, due to a short monitoring period of 2 to 3 days at baseline and 1-year, which may be insufficient to represent habitual PA in children (Trost et al., 2000). Interventions aiming to encourage healthy lifestyle behaviours at the community, school and family level therefore appear necessary for the prevention of childhood obesity (Eisenmann et al., 2008). However, few interventions are able to include multiple levels due to financial and organisational constraints, and instead focus on a single level, which has value in advising the potential development of multi-level approaches.

Alternative school-based interventions to prevent or reduce childhood overweight have targeted increased PA through a decrease in sedentary time. In the RCT of Robinson (1999), 8 to 12 year old children were encouraged to reduce their TV, videotape and video game use through eighteen lessons over a 6-month period. Lessons included self-monitoring of TV, videotape and video game use to motivate children to reduce time spent in these activities, and taught children to use their screen time more selectively in order to adhere with a TV budget. The TV budget was enforced by an allowance system that locked onto the power supply of TV sets and monitors. Compared to controls after 7 months, intervention children spent significantly less time watching TV and ate fewer meals in front of the TV, according to child and parent reports, and, spent significantly less time playing video games, according to child reports. These targeted changes were observed with reductions in BMI, triceps skinfold thickness, waist circumference and waist-to-hip ratio compared to controls, though no change in self-reported PA was evident. Gortmaker et al. (1999) similarly used a 2-year curriculum-delivered intervention to reduce TV use and promote PA and healthy eating in children aged 11 to 14 years. Compared to controls, the intervention reduced self-reported TV use in boys and girls. In girls, the intervention also increased self-reported fruit and vegetable consumption, attenuated the rise in energy intake, and, reduced the prevalence of obesity compared to controls. These observations were accompanied however with no significant increase in self-reported PA in boys and girls (Gortmaker et al., 1999).

These findings contrasted those observed from a 16-week health education intervention that used ten teacher-led lessons to reduce TV and computer use, and increase PA, in children aged 9 to 11 years from nine schools (Harrison et al., 2006). In one hundred and eighty two intervention children, changes in BMI and self-reported screen time post-intervention were not significantly different from one hundred and thirty age-matched controls (Harrison et al., 2006). However, self-reported time spent in MVPA and PA self-efficacy was significantly greater than controls (Harrison et al., 2006).

Conflicting results between the trial of Harrison et al. (2006) and those of Gortmaker et al. (1999) and Robinson (1999) may be due to differences in participants, intervention design and duration, and the level of engagement with the intervention. What these studies indicated though was that screen time and PA were poorly related, as a change in one variable was not accompanied by an equal or opposite change in the other. This supports suggestions that children have sufficient time for both PA and sedentary behaviours (Marshall et al., 2004). It is important to acknowledge, however, that conclusions from these trials are limited by a reliance on self-reported measures of PA. For example, in the trial by Robinson (1999) only previous day out-of-school PA and time spent in organised or unorganised activities were reported by children and parents, respectively.

A recent RCT by Epstein et al. (2008) provided objective PA data to support conclusions of Robinson (1999) and Gortmaker et al. (1999). In 4 to 7 year old children above the 75th BMI percentile for age and sex, an allowance system, which locked onto the power supply of TV sets and monitors, was used over 2 years to reduce TV and computer use by 50%. Following a 3-week baseline assessment of TV and computer use through the allowance systems, these systems were set up on a weekly time budget for the intervention child. Each month the time budget was reduced by 10% from the baseline value until the budget was reduced by 50%. A monitor could not be turned on once the time budget for a week was reached. Weekly financial incentives, parental praise and a star chart award system were also provided to encourage children to remain under budget. Significant between-group differences for TV and computer use at 6, 12, 18 and 24 months were observed with favourable BMI changes in intervention children compared to controls, despite no increase in total PA (CPM). A significant reduction in energy intake in intervention children compared to controls was also observed at 18 and 24 months. Thus, reduced access to sedentary screen-based behaviours had a beneficial effect on body composition in young people independent of PA, suggesting that screen time influenced obesity through increased energy intake, as previously suggested (Epstein et al., 1995; Ekelund et al., 2006). It should be acknowledged that this study was limited by only examining the influence of reduced screen time on total PA. Interventions effects on subcomponents of PA may be different to total PA (Robinson, 1999) and this should therefore be assessed in future trials.

In 10 to 11 year old children, Salmon et al. (2008) evaluated the effect of a nineteen lesson curriculum-based behaviour modification intervention, which aimed to reduce sedentary behaviours and promote PA. In contrast to Epstein et al. (2008), intervention children reported significantly greater TV use than controls at the end of the yearlong intervention and at 12-months follow-up. The authors suggested this may be due to lessons undesirably increasing children's awareness and engagement with TV, though an increased accuracy of reporting compared to controls, as a result of learning how to better monitor their viewing, may have biased these results (Salmon et al., 2008). A modest improvement in accelerometry-assessed moderate PA and a modest but significant improvement in vigorous PA and total PA were reported compared to controls post intervention and at 12 months follow up. This contrasted interventions reporting no increase in PA (Robinson, 1999; Gortmaker et al., 1999; Epstein et al., 2008). This was likely due to the inclusion of PA elements within lessons, such as the designing of physically active games and the teaching of PA health benefits and ways of increasing PA (Salmon et al., 2008). Nevertheless, despite increasing PA, intervention children did not have a significant reduction in BMI compared to controls. Only children randomised to a combined intervention that included behaviour modification lessons plus fundamental movement skill lessons, had a significant decrease in BMI post intervention and at follow-up compared to controls (Salmon et al., 2008). Given no significant change in PA or sedentary behaviour was observed compared to controls across the trial, the authors suggested this decrease in BMI may have been due to dietary or behavioural changes occurring during the trial that were not captured at the time of the assessment (Salmon et al., 2008). This unique evidence for the maintenance of intervention effects on body composition is not reported in previous trials (Robinson, 1999; Gortmaker et al., 1999; Epstein et al., 2008), and supports interventions targeting PA and decreasing sedentary behaviours.

Whilst interventions to reduce screen time have demonstrated positive changes in body composition, increases in habitual PA are rare and the long-term sustainability of these approaches, especially the restriction of media use through technologies such as a TV allowance system, is questionable. It is suggested that if significant others such as parents make choices that influence the behaviour of a child, for example installing an allowance system to limit TV or video game use, the child may not attribute the motivation for change to themselves (Epstein et al., 1995). Instead they attribute the behaviour change to parental control. This may influence their liking of the targeted change (i.e. reduced screen time) and the likelihood of sustaining this behaviour change when the treatment contingency (i.e. allowance system) is removed (Deci and Ryan, 1985). Conversely, if children are provided a choice and are able to attribute the motivation for change to themselves, as shown in studies on eating (Birch et al., 1984) and exercise choices (Orlick and Mosher, 1978), their liking and sustainment of the behaviour change may increase (Epstein et al., 1995). When considering screen-based media use, providing children with a choice rather than enforcing restriction seems important in today's technology driven environment. Appealing forms of sedentary entertainment are continually emerging, children are resistant to relinquishing screen-based activities (Faith et al., 2001; Wilson, 2007), and with age children have greater opportunity to visit friends' homes or arcades to accumulate TV and video game use if restricted at home (Epstein et al., 2008).

An alternative approach for reducing the time spent in sedentary screen-based activities whilst promoting PA may be to encourage PA during screen time in the home. This is supported by the home being described as an important context within which physically active behaviours can be encouraged and fostered (Owen et al., 2000), as young people spend a substantial proportion of the day at home where parents can reinforce positive behaviours. It has also been suggested that interventions to increase PA should preserve the context of existing behavioural preferences of the target population (Marshall et al., 2002), which for children would include the use of technology, specifically TV and video games. Olds et al. (2004) reiterated this by stating creative, innovative interventions need to use technology for active movement.

A way of fulfilling these criteria is to convert sedentary screen-based activities into physically active pursuits. Active video games encourage PA and discourage sedentary behaviour compared to sedentary video games. If active video games became as much a part of the typical child's routine as sedentary video games and other sedentary entertainment are now, they could be a useful tool for promoting indoor active play and regular PA and EE (Pate, 2008). In line with Welk's (1999) ecological approach, the provision of active video games would enable young people to be physically active and parental and sibling support can reinforce the conversion of video game time from sedentary to active. Children and adolescents' affinity with video games and the basic movements typically required during active video gaming may encourage the perception that they are able to participate in the activity with success. Furthermore, aided by such a perception and support from significant others, young people may perceive participation in active video gaming as worthwhile. Though targeting all modifiable factors is optimal for PA promotion, the current thesis will focus on predisposing and enabling factors. Reinforcement from parents to encourage their child to convert gaming from sedentary to active will occur at the start of the home-based intervention in this thesis. However, the inclusion of a continual strategy to encourage sustained parental reinforcement is beyond the scope of this thesis due to limited resources. The demographic factor of SES will be used to target children for the home-based intervention.

2.6 Active video gaming in youth

Sedentary video gaming is a dominant leisure pursuit in young people's lives (Marshall et al., 2006). Video games are popular as they are complex, immersive (i.e. encourage deep involvement) and provide graded challenges by adapting the level of play based on the improving skill of the individual (Vorderer et al., 2004; Sherry, 2004; Wood et al., 2007). These characteristics have been reported in children, adolescents (Griffiths and Hunt, 1995; Phillips et al., 1995), and adults (Wood et al., 2007), to encourage a 'one more go' mindset and prolonged gaming sessions. Video games have been found to absorb an individual's attention to the extent that they lose track of time irrespective of gender, age or frequency of play (Wood et al., 2007). For many gamers, losing track of time was the main reason for playing video games, as it helped them to relax and temporarily escape from reality, though some indicated loss of time to have negative outcomes such as wasted time, the sacrificing of other things in their lives such as classes, coursework and meetings, and, social conflict with friends and family (Wood et al., 2007).

Recent advances in technology have provided opportunities to enable gamers to engage in video gaming in an active manner. If gamers find active video games as immersive as sedentary video games, and substitute them into their routine without reducing PA away from the screen, a potentially large reduction in daily sedentary time and increase in EE can be achieved. This hypothesis is supported by laboratory-based studies examining the physiological responses to playing sedentary and active video games. Early work by Segal and Dietz (1991) found that compared to standing still, standing play on an arcade video game in laboratory conditions significantly increased HR, oxygen consumption ($\dot{V}O_2$) and blood pressure in thirty-two young adults aged 16 to 25 years. Ridley and Olds (2001) later reported the energy cost of four arcade video games to range from light to vigorous intensity in ten children aged 11 to 12 years, with a positive association between EE and PA measured by a hip-mounted accelerometer. This association disappeared, however, when data for the most active video game, which required whole body movements, were removed, with the authors concluding uniaxial accelerometers as unsuitable for quantifying the energy cost of video games (Ridley and Olds, 2001). This conclusion is limited however, as the remaining three video games required upper-limb movements, which are poorly captured by hip-mounted accelerometers (Rowlands, 2007). This would suggest that to quantify the energy cost of non-ambulatory video games, assessment of upper limb PA is required.

Wang and Perry (2006) found sedentary video gaming in a laboratory to significantly increase HR, $\dot{V}O_2$ and blood pressure compared to seated rest in twenty-one boys aged 7 to 10 years. The authors concluded that sedentary video gaming was not a passive activity and should not be combined with TV for the evaluation of sedentary behaviours (Wang and Perry, 2006). Marshall et al. (2004) shared this view, having stated that screen-based behaviours need to be isolated in associations with PA and health. The light intensity energy cost of seated gaming was further concluded as lower than that elicited by exercise (Wang and Perry, 2006), which though logical to assume, was based on comparisons with data from previous literature and not data from repeated measurements in the sample. No empirical research comparing physiological responses between active or sedentary video gaming and exercise in the same sample currently exists. This would further contextualise the energy expending potential of video games.

It was evident from these initial studies that video games stimulate significant metabolic and physiologic responses in young people and adults, and this has been similarly reported for recently developed active video games. Lanningham-Foster et al. (2006) found playing video games for 15 min using a hand-held controller while seated to increase EE above resting values by 22% in twenty-five children aged 8 to 12 years. Conversely, active video games that primarily encouraged upper body movements (Nicktoons Movin'®, EyeToy®, Sony Computer Entertainment, San Mateo, CA) and lower body movements (Dance Dance Revolution (DDR) Ultramix 2®, Konami Digital Entertainment, Redwood City, CA) increased EE above rest by 108% and 172%, respectively (Lanningham-Foster et al., 2006). Significant increases in EE from resting values to light to moderate intensities during active video gaming compared to sedentary gaming were consistent between lean and overweight children (Lanningham-Foster et al., 2006). Unnithan et al. (2006) similarly reported no difference in $\dot{V}O_2$ relative to body mass, stature and fat-free mass, or the percentage of peak and average $\dot{V}O_2$ and HR, between non-overweight and overweight youth aged 11 to 17 years during laboratory-based play on a dance game (DDR). These results suggest the submaximal energy cost of movement during active video gaming is consistent across varying levels of adiposity (Unnithan et al., 2006; Lanningham-Foster et al., 2006).

Unnithan et al. (2006) further presented two important findings. First, based on a HR maximum (HR_{max}) percentage of 65%, which equates to moderate intensity activity in adults (US Department of Health and Human Services, 1996), DDR was concluded sufficient for developing or maintaining cardiorespiratory fitness in youth, similar to previous work (Tan et al., 2002), as it exceeded the American College of Sports Medicine (ACSM) recommendation of 60% HR_{max} (Pollock et al., 1998). However, this recommendation is for adults, with Baquet et al. (2003) indicating exercise intensities greater than 80% HR_{max} are necessary to improve cardiorespiratory fitness in youth. The greater exercise intensity for youth may be due to a relatively high initial peak $\dot{V}O_2$ compared to adults, which would contribute to a decreased sensitivity to training (Baquet et al., 2003; Rowland, 1992), and suggests that dance games are insufficiently intense to maintain cardiorespiratory fitness. Secondly, during DDR there was a disassociation between HR and $\dot{V}O_2$, with $\dot{V}O_2$ failing to increase to the same proportion as HR. Unnithan et al. (2006) hypothesised this was due to a lack of upper body movement during dance simulation. However, in twenty-one children aged 10 to 14 years, play on an active video game (Homerun®, Sony EyeToy) that required upper and lower body movements was reported to elicit an energy cost similar to that during dance simulation (Maddison et al. 2007). Therefore, the disassociation may be due to the intermittent nature of active video gaming, with rest periods leading to transient decreases in HR and $\dot{V}O_2$, as suggested by Unnithan et al. (2006). This would imply that more continuous active video game play is necessary to avoid a disassociation between HR and $\dot{V}O_2$. Whether children enjoy continuous active video game play is questionable however, as this would not match the intermittent nature of their PA patterns and may be too physically demanding.

Similar to the study of Lanningham-Foster et al. (2006), Maddison et al. (2007) found active video gaming on the EyeToy and a dance game to significantly increase PA and EE compared to sedentary video games in twenty-one children aged 10 to 14 years. Furthermore, the games Homerun, Knockout® and Cascade®, and Dance UK® on the PlayStation® (PS) 2 (Sony Corporation, Tokyo, Japan) elicited moderate PA intensities ($\geq$ 3 METs) that would contribute towards daily recommendations for child and adolescent PA (Maddison et al., 2007). Beyond these studies however, which focused on similar games, little is known about the physiological cost of other commercially available active video games and devices young people use.

The physiological responses to active video gaming have to date not been compared in the same sample of participants to activities of daily living, which would contextualise the energy expending potential of active video games. Research is also generally limited to youth aged 6 to 16 years, with little or no reported study investigating the physiological responses to active video gaming in young and older adults. This would provide an indication as to which age group may benefit the most, from an EE perspective, from playing active video games. This may inform the target population for interventions using active video games to promote PA and health. Assessing physiological responses to active video gaming across a wide age range would also indicate whether the magnitude of PA and EE observed in young people is similar in adults. If similar physiological responses were observed across different age groups, this would support the promotion of active rather than sedentary video gaming throughout the lifecourse. In the published literature no empirical research has documented the contribution of upper limb and total body movement to EE during active video gaming. This would generate PA data that can be used to support conclusions as to why active video games stimulate different increases in activity levels and the associated physiological costs. This research question can be addressed through PA monitoring at the hip and wrist via accelerometers. This will also provide recommended data on the value of assessing upper limb movements in addition to total body, for the accurate prediction of EE in young people during unique, non-ambulatory activities (Trost et al., 2005).

An additional limitation of the published literature is that it is relatively unknown whether young people enjoy active video gaming. Enjoyment and free choice are valued traits when choosing to participate in an activity (Dishman et al., 2005). Investigating whether enjoyment of active video gaming is similar to seated equivalents is pertinent in order to gain an insight into the potential sustainability of these devices. Epstein et al. (2007) found that when given the opportunity to play a dance video game (DDR) actively or seated using a hand-held controller, eighteen overweight and seventeen non-overweight 8 to 12 year old children were more motivated to select the active alternative in a laboratory setting. The same was not observed for a bicycle video game however (Epstein et al., 2007). A preference for the active dance game may have been due to its interactive nature, perhaps both physically and mentally, with children less motivated to play the active bicycle game as it felt too much like exercise or was too physically demanding (Epstein et al., 2007). Using a hand-held controller as an alternative to actively cycling may have also been more appealing, as it was similar to usual video game play (Epstein et al., 2007).

These findings suggested that for young people to choose to play active video games, the relative reinforcing value of the game (i.e. the desirability of the outcome of the behaviour) needs to be greater than that of available alternatives, such as seated gaming (Epstein and Saelens, 2000). This may entail that the intensity of active video gaming should not be too great, otherwise physical sensations may override enjoyment, make us avoid the outcome from the behaviour and reduce participation. This is supported by research that reported physical feedback during video gaming, such as manipulating a joystick, to act as a 'reality check' that reminded adolescent and adult video game players of their physical surroundings and prevented immersion (deep involvement) in the game and concomitant sensations of time loss (Wood et al., 2004; Wood et al., 2007). Despite the encouraging reports that young people may choose to allocate time to active video gaming (Epstein et al., 2007), information on the enjoyment of other active video games compared to sedentary equivalents in youth and adults is lacking. Furthermore, observations were from a short period of game play in a laboratory setting, with a paucity of research investigating how long and for how often young people play active video games in the home.

Chin A Paw et al. (2007) conducted a 12-week intervention to investigate the motivation of thirteen children aged 9 to 12 years to play an interactive dance video game, provided for home use, on a computer. Despite initial interest in the game, children's median self-reported weekly playing duration decreased from 228 min at 6 weeks to 0 min at 12 weeks (Chin A Paw et al., 2007). Reasons for not playing regularly included dull music, boredom of the game, the need for space in front of the computer and technical faults with the game (Chin A Paw et al., 2007). In contrast, fourteen children invited to participate in a weekly multiplayer interactive dance class, in addition to home use of the dance video game, had a self-reported increase in median playing duration from 475 min at week 6 to 601 min at week 12 (Chin A Paw et al., 2007). This suggested the multiplayer class increased children's motivation to sustain active video gaming in the home, possibly by increasing the reinforcing value of the game compared to available alternatives (Epstein et al., 2007). Competition between children within the class may also have increased their motivation to practise at home. Alternatively, the difference in playing duration may be explained by the intervention group being leaner than the home group. Other limitations of this trial included small sample sizes that were not gender balanced, a failure to objectively measure changes in habitual PA, the absence of a comparison group to compare intervention effects against, and, the use of a computer rather than TV as the output media for the video game, with Wood et al. (2004) reporting that poor graphics and sound effects can reduce enjoyment during video gaming.

Madsen et al. (2007) similarly investigated self-reported use of a dance simulation game (DDR) provided for home use in thirty 9 to 18 year olds from a paediatric obesity clinic. At 3 months only twelve of twenty-six children who provided follow-up data used DDR at least twice a week, with this decreasing to two of twenty-one children at 6 months (Madsen et al., 2007). Playing DDR was suggested to be insufficiently motivating to yield sustained use, and children reported that playing with friends, competitions and a greater variety of music may increase use of the game and alleviate sensations of boredom (Madsen et al., 2007). Though this study was limited by failing to assess habitual PA across the trial, and failing to compare intervention effects against a comparison group, findings supported those of Chin A Paw et al. (2007). Dance simulation games therefore appear insufficiently complex, immersive or graded in terms of game play difficulty to maintain motivation for sustained use, placing doubt over the ability of active video games to promote regular PA and health in young people.

Children and adolescents in these studies were provided with dance simulation games for use on a specific console, with the effect of other active video games on PA, sedentary behaviour and health unknown. Further, similar to any sedentary video game, provision of a single active video game is likely to have contributed to decreased motivation for sustained use due to over-familiarisation (Mellecker et al., 2008). An alternative approach may therefore be to provide a range of active video games to young people. Conversely, there is growing evidence to suggest that re-engineering PA into the video games young people already own and play may be an effective strategy for promoting PA and decreasing sedentary behaviour (Levine, 2007; Mellecker et al., 2008). With respect to the discussed limitations of previous interventions, there is a need for more RCTs to investigate the effect of active video games or devices on PA, sedentary behaviour and health in young people.

2.7 Summary

This review has highlighted the health benefits of increased PA and reduced sedentary time in young people. Though the prevalence of children and adolescents meeting current guidelines for health enhancing PA is unknown, PA declines from childhood to adolescence and many young people exceed screen time recommendations. The rising incidence of overfat and obesity in young people further indicates that preventive action against low levels of PA and excessive weight gain is necessary from an early age. The limited success of school-based interventions to increase habitual PA and improve health, and the complexity and cost of multi-level interventions, suggest innovative approaches may be required to help promote positive behaviour change and energy balance in youth, whilst informing larger trials. One such approach for promoting PA and reducing sedentary time is to use technology to convert screen time from sedentary to active in the home. This will allow young people to continue participating in screen-based behaviours that they enjoy, and may have greater long-term sustainability than interventions restricting screen time through parental control.

Active video games combine PA with video gaming and have been reported in cross-sectional research to significantly increase PA and EE in children and adolescents compared to sedentary video gaming and rest, with PA intensities typically light or moderate. However, much more needs to be known. The active video games investigated in the published literature have focused on a small range of activities, with the physiological cost of other commercially available games and devices unknown. No empirical research documents the contribution of upper limb and total body movements to EE during active video gaming. This can be achieved through multi-site activity monitoring and will allow evidence-based conclusions to be made as to why active video games elicit different increases in PA and EE. This approach will also provide recommended information on the value of assessing upper limb movements in addition to total body for the accurate prediction of EE in young people during non-ambulatory activities. There is limited research investigating the physiological responses to, and enjoyment of, active video gaming in children and adults compared to sedentary video gaming and other physical activities. This would provide an insight into the potential acceptability of these games and inform whether the magnitude of PA and EE observed in young people is similar in adults. This would help inform whether interventions seeking to substitute sedentary video games for active equivalents are suitable, and provide an indication as to which age group is best to target for interventions using this technology to promote PA and health. Comparable magnitudes of PA and EE across age groups would provide further support for the lifelong conversion of video gaming from sedentary to active. Few interventions have investigated the effect of active video gaming on PA and sedentary behaviour in young people, with previous interventions in youth limited by failing to assess intervention effects relative to a comparison group and failing to objectively assess changes in habitual PA. Randomised controlled trials and controlled trials are warranted to determine if young people will substitute sedentary video gaming for active video gaming over time, and in doing so, whether a reduction in sedentary time and increase in habitual PA will accrue health benefits.

2.8 Major aims of the thesis

A review of the discussed literature led to the formation of the major aims of this thesis. Aim 1 is to compare adolescents' EE whilst playing sedentary video games and active video games on the Nintendo Wii® (Nintendo Co Ltd, Minami-ku Kyoto, Japan) video game console. This will provide original data on the energy cost of active video games other than those on the Sony EyeToy or a dance simulator, and allow findings to be contextualised in relation to sedentary equivalents and PA guidelines. Aim 2 is to examine the contribution of upper limb and total body movement to adolescents' EE whilst playing non-ambulatory active video games. The use of multi-site accelerometry will provide an indication of the value of assessing upper limb movements in addition to total body for the accurate prediction of EE during non-ambulatory activities, and will be compared to predictions from the more utilised approach of combined HR and movement sensing.

Aim 3 is to assess the physiological cost and enjoyment of active video gaming in adolescents, and young and older adults, and to compare findings with those for sedentary video gaming and aerobic activities common to daily living (walking and jogging). This study will inform whether the magnitude of PA and EE during active video gaming is similar across a spectrum of ages and gaming experience and provide an insight into the potential acceptability of these devices. This will inform the suitability of using active video games as an interventional tool for promoting PA in youth and throughout the lifecourse. Aim 4 is to investigate, through a RCT, the short-term effects (12 weeks) of active video gaming on children's habitual PA and sedentary behaviour, behaviour preferences, and, body composition, with a mid-test analysis incorporated at the 6-week period. This will be one of the first trials to provide an insight into whether young people play active video games other than dance simulators in the home over time, and whether in doing so this will encourage a reduction in sedentary time, an increase in habitual PA and any associated health benefits.

Aim 1: To compare adolescents' EE whilst playing sedentary video games and new generation active video games in a laboratory setting – Chapter 3.

Aim 2: To examine the contribution of upper limb and total body movement to adolescents' EE whilst playing non-ambulatory active video games in a laboratory setting – Chapter 4.

Aim 3: To compare the physiological cost and enjoyment of active video gaming with sedentary video gaming and aerobic exercise in adolescents, and young and older adults in a laboratory setting – Chapter 5.

Aim 4: To evaluate the short-term (12 weeks) effects of a home-based active video gaming intervention on children's habitual PA and sedentary time, behaviour preferences, and, body composition, with a mid-test analysis incorporated at the 6-week period – Chapter 6.

Chapter 3

Comparison of Energy Expenditure in Adolescents when Playing a Sedentary Video Game and New Generation Active Video Games

Comparison of energy expenditure in adolescents when playing a sedentary video game and new generation active video games

The main outcomes of this study have been published in the British Medical Journal (Graves, L., Stratton, G., Ridgers, N. D., Cable, N. T. (2007). Comparison of energy expenditure in adolescents when playing new generation and sedentary computer games: cross sectional study. *British Medical Journal,* **335,** 1282-1284) and the British Journal of Sports Medicine (Graves, L., Stratton, G., Ridgers, N. D., Cable, N. T. (2008). Energy expenditure in adolescents playing new generation computer games. *British Journal of Sports Medicine,* **42,** 592-594) (please see Appendix 2).

3.1 Introduction

Higher levels of PA in youth are associated with more favourable cardiovascular and metabolic disease risk factor profiles (Andersen et al., 2006; Ekelund et al., 2007), which can extend into adulthood (Nicklas et al., 2002; Bao et al., 1994; Lambrechtsen et al., 1999). Young people are therefore recommended to engage in at least 60 $min{\cdot}d^{-1}$ of MVPA (Biddle et al., 1998; DH, 2004), although 120 $min{\cdot}d^{-1}$ for children and 90 $min{\cdot}d^{-1}$ for adolescents may be necessary (Andersen et al., 2006). Moderate intensity PA should use at least three times as much energy as is used at rest (Biddle et al., 1998; DoH, 2004). Despite these recommendations, there is concern that many children are insufficiently active to benefit their health (Riddoch et al., 2007); although the percentage of youth deemed sufficiently active is dependent on the accelerometer activity count cut point used to define moderate PA. The decline in PA seen during adolescence further places children's future health in jeopardy (Biddle et al., 2004b; Strong et al., 2005).

Many factors contribute to low levels of PA and the excess accumulation of adiposity in young people, with links made to the time spent engaged in sedentary screen-based behaviours such as TV viewing and video game or computer use (Vandewater et al., 2004; Marshall et al., 2004). While there is evidence to suggest increased TV viewing is associated with obesity, video games and computers are not thought to represent such a high risk (Rey-Lopez et al., 2008). It has even been suggested that replacing TV viewing with sedentary video gaming may positively affect EE (Wang and Perry, 2006).

However, research suggests that time spent sedentary (< 500 CPM) is positively associated with metabolic risk in children and adolescents (Ekelund et al., 2007). Moreover, high media use in childhood is linked to high use in adolescence (Marshall et al., 2006), and 5 to 12 year olds who self-reported to spend more than 2 $h \cdot d^{-1}$ watching TV and playing video games were at greater risk for overweight than peers accumulating less than 2 $h \cdot d^{-1}$ (Laurson et al., 2008; Spinks et al., 2007). This would support the theory of sedentary behaviour as a modifiable risk factor for lifestyle related diseases (Blair and Connelly, 1996). Targeting reductions in sedentary time and increasing PA therefore seem beneficial to child and adolescent health.

The new generation of wireless based video games are meant to stimulate greater movement during video gaming. A recent study reported that playing video games for 15 min using a hand-held controller while seated increased EE over resting values by 22% in twenty-five children aged 8 to 12 years (Lanningham-Foster et al., 2006). However, an active video game that required upper body movements (Sony EyeToy) and a dance simulation game (DDR) increased EE by 108% and 172% over resting values, respectively (Lanningham-Foster et al., 2006). Maddison et al. (2007) found active video gaming on the EyeToy and a dance game to significantly increase EE compared to sedentary video games in twenty-one children aged 10 to 14 years, with moderate PA intensities recorded during play on the games Homerun, Knockout and Cascade (EyeToy) and Dance UK (PS2). Thus, the new generation of active video games could be a useful addition to the range of opportunities for PA available to young people, which may help curb the rising incidence of obesity and support more young people to meet PA recommendations (NICE, 2006; Mohebati et al., 2007; Nilsson et al., 2009).

Youth in affluent countries spend 30 to 45 $min \cdot d^{-1}$ playing video games and using computers (Woodward and Gridina, 2000; Marshall et al., 2006). In the UK, 75% of children and adolescents have been reported to play sedentary video games for 6 to 14 $h \cdot wk^{-1}$ (Pratchett, 2005). Reports suggest it is difficult to persuade children and adolescents to relinquish screen-based activities however (Faith et al., 2001; Wilson, 2007). Therefore, if all or some of the time young people spend playing sedentary video games could be replaced with time spent playing active video games, then video games have the potential to increase regular PA and EE in the home. The active video game

Wii Sports® (Nintendo Wii, Nintendo Co Ltd, Minami-ku Kyoto, Japan) was developed in 2006 and encourages active screen time. No information is currently available on the activity levels of young people when playing this new generation video game. The aim of this study was to investigate the EE of adolescent boys and girls whilst playing Wii Sports, and to compare findings to those observed during sedentary video gaming.

3.2 Method

3.2.1 Participants and setting

A convenience sample of five girls and six boys aged 13 to 15 years participated in the study. Participants were recruited from a PE lesson at a local school, and all were competent at sport; they regularly represented their school at hockey or netball (girls) and rugby or football (boys). Data from a video gaming experience questionnaire (please see Appendix 1) completed during the familiarisation visit indicated that the mean (SD) reported time spent playing video games for boys and girls was 6.4 (6.4) and 3.6 (2.3) $h \cdot wk^{-1}$, respectively, and none had previously used the Nintendo Wii. Parents and adolescents provided written informed consent and assent, respectively, to participate in the study, which was approved by the University ethics committee. All measures were taken in the laboratories at the Research Institute for Sport and Exercise Sciences (RISES, Liverpool John Moores University).

3.2.2 Procedure

3.2.2.1 Anthropometry

Using standard anthropometric techniques, stature was measured to the nearest 0.1 cm using a portable stadiometer (Leicester Height Measure, Seca Ltd, Birmingham, UK) and body mass to the nearest 0.1 kg using a calibrated mechanical flat scale (Seca Ltd, Birmingham, UK) with participants wearing light clothing and without shoes (Lohman et al., 1991). Body mass index (BMI) was calculated as mass divided by stature ($kg \cdot m^{-2}$).

3.2.2.2 Resting measurements and familiarisation

On separate days to experimental trials, and following at least 2 h of fasting and 5 min of supine rest, resting $\dot{V}O_2$ was measured for 6 min in a quiet darkened room using a portable MetaMax 3B indirect calorimetry system (Cortex, Biophysik, Leipzig, Germany) and accompanying facemask (Hans Rudolf, Kansas City, MO, USA). This measurement duration is consistent with previous research and provides sufficient time for children and adolescents to achieve a steady state (Unnithan et al., 2006; Maddison et al., 2007).

Participants were familiarised with the sedentary video game Project Gotham Racing 3® (PGR3, XBOX 360®, Microsoft, Redmond, WA; http://projectgothamracing3.com) and the active video games of bowling, tennis and boxing on Wii Sports (http://us.wii.com/wiisports/). Project Gotham Racing 3 is an arcade-style racing game, which is typically externally-paced as participating players race against central processing unit (CPU) opponents around various courses over a set distance. Through a wireless handheld controller, players use the analog or directional pad (D pad) to steer, and standard buttons to accelerate/decelerate, among other actions. A race finishes when the player completes the required number of laps or is timed out. Wii Sports consists of five separate sports games (tennis, baseball, bowling, golf, boxing). A player uses the motion sensor capabilities of the wireless handheld Wii Remote and Nunchuk attachment to control the actions of the onscreen character, moving the remotes in a similar manner to how the separate games are played in real life. The Wii Remote is the primary controller for the Nintendo Wii, and the Nunchuk is a secondary controller that connects to the Wii Remote via a cord (1 to 1.2 m long) and expansion port at the bottom of the Wii Remote. The Wii Remote is held in the dominant hand.

For PGR3, seated participants used the wireless handheld controller to complete two races on a single player race mode. For Wii Sports, standing participants completed the training modes for bowling, tennis, and boxing. The mean (SD) total duration of the familiarisation session was 42.4 (4.1) min (XBOX 360 13.4 (4.4) min; bowling 11.4 (2.5) min; tennis 8.2 (2.3) min; boxing 9.5 (1.4) min). The order of gaming familiarisation was not randomised. All participants were right handed and the active video games were set up to accommodate this. The participant's dominant hand was deemed the hand they wrote with. During familiarisation participants wore an Intelligent Device for Energy Expenditure and Activity system (IDEEA, Minisun LLC, California, USA) and a portable MetaMax 3B system with an accompanying facemask.

3.2.2.3 Experimental trial

Each participant performed one experimental trial. Participants were only fitted with an IDEEA system due to equipment failure with the MetaMax 3B system. Each participant first played on PGR3 seated for 15 min. Participants then stood and played competitive bowling, tennis and boxing games on Wii Sports for 15 min each, as recommended by Nintendo, in the order stated. Each activity was interspersed with 5 min of seated rest. Once a race or game was completed the event was restarted and this continued for the 15 min. Each participant played for a total of 60 min.

For PGR3 participants competed against central processing unit (CPU) opponents over three-lap races. For Wii Sports participants began on zero skill points (easiest level of competition) and progressed through the game as dictated by the number of points they were awarded for a game (tennis), three-round bout (boxing), or ten-lane game (bowling). Points were awarded by the console for their level of performance during the previous game (e.g. higher points awarded for knock-out in boxing compared to three-round win). For boxing, participants held the Wii Remote and Nunchuk in the dominant and non-dominant hand, respectively. Boxing was an externally-paced game, as participants boxed against a CPU opponent, using both arms to throw punches towards the screen whilst evading or blocking their opponent's punches by moving the remotes from side to side or bringing them together. For tennis, the Wii Remote was held in the dominant hand and used to play tennis shots, such as a forehand, backhand, volley or smash, to win points. Tennis was externally-paced, as participants played alongside a CPU partner against two CPU opponents. For bowling, participants held the Wii Remote in the dominant hand and used their arm to bowl in a traditional ten-pin format on their own. This game did not involve an opponent and as such was self-paced. A range of movements were observed during play on all Wii Sports games, from actions similar to those observed during authentic versions of the games, to small motions produced by flicking the wrists back and forth.

3.2.3 Instrumentation

3.2.3.1 Gas analysis

Expired air was measured during the resting protocol using a portable MetaMax 3B. The MetaMax 3B is a fully portable gas-exchange system with telemetry capability, and can measure breath-by-breath $\dot{V}O_2$ and HR by indirect calorimetry and integrated electrocardiography (ECG) monitoring, respectively. Data measured are recorded using MetaMax software (Statera Edition, Version 3). The system allows unrestricted movement during physical activities for children and adults, and has been used in youth studies (Maddison et al., 2007). The device has been found to provide valid (Larsson et al., 2004; Meyer et al., 2005) and precise (Medbø et al., 2002) metabolic gas measurements compared to the Douglas Bag technique and stationary metabolic carts. When placed on participants, the two main components of the device sat on the upper chest and were secured firmly to the body by the connecting cord and assisting straps. An appropriately sized facemask covering the nose and mouth was secured via an adjustable nylon harness, and participants were instructed to breathe normally into the mask. The bidirectional digital turbine flow meter inserted into the facemask and measured the volume of inspired and expired air. A sample line connecting the turbine and analyser unit determined the content of O_2 and CO_2.

Before each use a guideline (Cortex Biophysik MetaMax 3B users manual) recommended calibration procedure was conducted. Gas sensors were calibrated against known concentrations of gases (4% CO_2 and 16% O_2), respiratory volume was calibrated using a 3 l syringe, and ambient air measurements were conducted repeatedly. Throughout the resting period $\dot{V}O_2$ data was averaged over 15-s epochs. Raw data for each measurement period were exported from the manufacturer software in 15-s epochs and analysed on a personal computer.

3.2.3.2 Physical activity and energy expenditure

During the experimental trial EE was predicted using an IDEEA system. The IDEEA is a microcomputer-based portable PA measurement device that consists of five small sensors (each 16 x 14 x 4 mm) located on three thin and flexible wires (2 mm outer diameter) that connect to a small 200 g data collection device (recorder) worn on the waistband (Zhang et al., 2003). The five sensors were attached using porous hypoallergic medical tape at the following locations: the sternum (4 cm below the clavicle), the midline of the anterior aspect of each thigh, and the underside of each foot on the outside arch (MiniSun users manual).

The sensors measure the angle and acceleration of body segments, and send output signals to the microcomputer in the recorder. The combinations of signals from the sensors are then processed by a microprocessor, to distinguish among different postures and gaits, and are stored in flash memory, along with participant age, gender, stature and body mass data. Data are then downloaded and processed using ActView (MiniSun, Fresno, CA). This Windows based programme provides second-by-second information on the type (e.g. sitting, standing, walking, jogging) and duration of activities, outcome measures including EE, speed, distance and power output, and allows raw data to be exported in time intervals (epochs) ranging from 1/32-s to 1-h (Zhang et al., 2003).

In seventy-six participants aged 13 to 72 years (mean age (SD) 36.3 (14.9) years) the IDEEA has been reported to have correct identification rates of 98% for a variety of daily activities, including posture, limb movement and gait type, compared to observations recorded by two researchers (Zhang et al., 2003). Sitting, standing and leaning were detected by the IDEEA with 99% accuracy, and high correlations (r = 0.99, $p < 0.001$) between predicted and actual walking and running speeds were observed. Energy expenditure predictions from the IDEEA were found to be 99% accurate and significantly correlate ($r = 0.97, p < 0.0001$) with EE measured by a mask calorimeter in twenty-seven, 15 to 61 year olds (33.7 (13.8) years) performing a protocol of sitting, standing, and, walking and running at various speeds (Zhang et al., 2004). Energy expenditure estimations were observed as 95% accurate compared with estimates from a metabolic chamber in ten participants aged 20 to 53 years (32.9 (12.4) years) who performed treadmill exercise, and, sat and ate meals over a 23-h period in the chamber. The accuracy of IDEEA EE estimations were not significantly affected by age, body mass, stature or BMI. These studies demonstrated that the IDEEA can accurately detect the type, and estimate the intensity of, several daily activities in adolescents and adults.

Before data collection began, participant age, gender, body mass and stature data were entered into the IDEEA software for calibration. Device calibration followed manufacturer instructions. The recorder, worn on the right waistband, was connected to a personal computer and participants were asked to sit still in an upright position with feet and thighs parallel to the floor and the upper body in a vertical position, for 10 to 20 s. A maximal deviation of 15 degrees for sensors is allowed. If the calibration failed the sensors were realigned based on feedback from the software and this process was repeated until successful. The device was worn throughout a trial, and after each trial data were downloaded and processed using ActView. Raw data for each activity were then exported in 10-s epochs and analysed on a personal computer. The same IDEEA unit was used for all participants.

3.2.4 Data handling and statistical analyses

Mean resting $\dot{V}O_2$ ($l \cdot min^{-1}$) was calculated by averaging the last 2.5 min of data during the resting phase. This data handling approach has been used in youth studies (Unnithan et al., 2006; Maddison et al., 2007). Mean $\dot{V}O_2$ values at rest were converted into EE ($J \cdot kg^{-1} \cdot min^{-1}$) using participant body mass and the established constants of 1 l O_2 = 4.9 kcal and 1 kcal = 4.18 kJ (McArdle et al., 1991). The outcome measure of EE from the IDEEA is in $kcal \cdot min^{-1}$. For each activity, mean predicted EE (EE_{pred}; $kcal \cdot min^{-1}$) was calculated using all data collected during the 15 min of gaming. The subsequent mean was then converted from $kcal \cdot min^{-1}$ to $J \cdot kg^{-1} \cdot min^{-1}$ using participant body mass and the constant 1 kcal = 4.18 kJ (McArdle et al., 1991). Participant-specific MET values were calculated for each video game by dividing the mean EE_{pred} of the activity by REE.

Independent samples t-tests were used to compare descriptive data between genders. Energy expenditure data were analysed using a two-group mixed-design analysis of variance (ANOVA) with gender (*boys, girls*) as the between-groups factor and activity (*rest, sedentary video game, Wii bowling, Wii tennis, Wii boxing*) as the within-groups factor (Field, 2000). Mauchly's test indicated sphericity was not violated ($p > 0.05$) (Field, 2000). In the presence of a significant main effect for gender or activity, post hoc pairwise comparisons with a Bonferroni correction for type I error control were investigated (Field, 2000). If the gender x activity interaction was significant, independent t-tests were performed amongst pairwise group means with a Bonferroni correction for type I error control (Atkinson, 2002). The Statistical Package for the Social Sciences (SPSS) v14 (SPSS Inc, Chicago, USA) was used for statistical analyses, with statistical significance set at $p \leq 0.05$. The results are expressed as means and standard deviations (SD).

3.3 Results

3.3.1 Descriptive analyses

The descriptive data of participants are shown in Table 3.1. Boys were significantly older, taller and heavier than the girls ($p < 0.05$).

3.3.2 Main analyses

Table 3.1 shows the REE and EE_{pred} of each activity by gender and for the group. Figure 3.1 shows the variability in REE and EE_{pred} across participants during gaming.

Table 3.1 Mean (SD) descriptive characteristics and energy expenditure (EE) of participants.

	All (n=11)	**Boys (n=6)**	**Girls (n=5)**
Age (years)	14.6 (0.5)	14.9 (0.3)	14.3 (0.5) *
Body mass (kg)	60.4 (8.8)	65.4 (8.5)	54.4 (4.7) *
Stature (m)	1.69 (0.1)	1.78 (0.05)	1.59 (0.04) *
BMI ($kg \cdot m^{-2}$)	21.2 (2.5)	20.7 (2.6)	21.7 (2.6)
EE ($J \cdot kg^{-1} min^{-1}$)			
REE	81.3 (17.2) **	83.0 (21.5) **	79.3 (12.4) **
EE_{pred}			
XBOX 360	125.5 (13.7) ***	127.9 (13.2) ***	122.6 (15.3) ***
Wii Sports bowling	190.6 (22.2)	201.8 (16.3)	177.2 (22.2)
Wii Sports tennis	202.5 (31.5)	222.2 (23.4)	178.9 (22.8)
Wii Sports boxing	198.1 (33.9)	206.8 (23.8)	187.7 (43.9)

* $p < 0.05$ (different from Boys)
**$p < 0.01$ (different from XBOX 360, bowling, tennis, boxing)
*** $p < 0.01$ (different from bowling, tennis, boxing)
BMI = body mass index; REE = resting energy expenditure; EE_{pred} = predicted energy expenditure.

The two-group mixed-design ANOVA resulted in a significant main effect for activity for EE (F = 84.66, p < 0.001). All video games significantly increased EE_{pred} above REE (p < 0.01; Table 3.1; Figure 3.1). For all Wii Sports games EE_{pred} was significantly greater than the sedentary video game (p < 0.01). The main effect for gender for EE approached statistical significance (F = 4.41, p = 0.065), with EE greater in boys than girls. There was no significant gender x activity interaction (F = 1.96, p = 0.122).

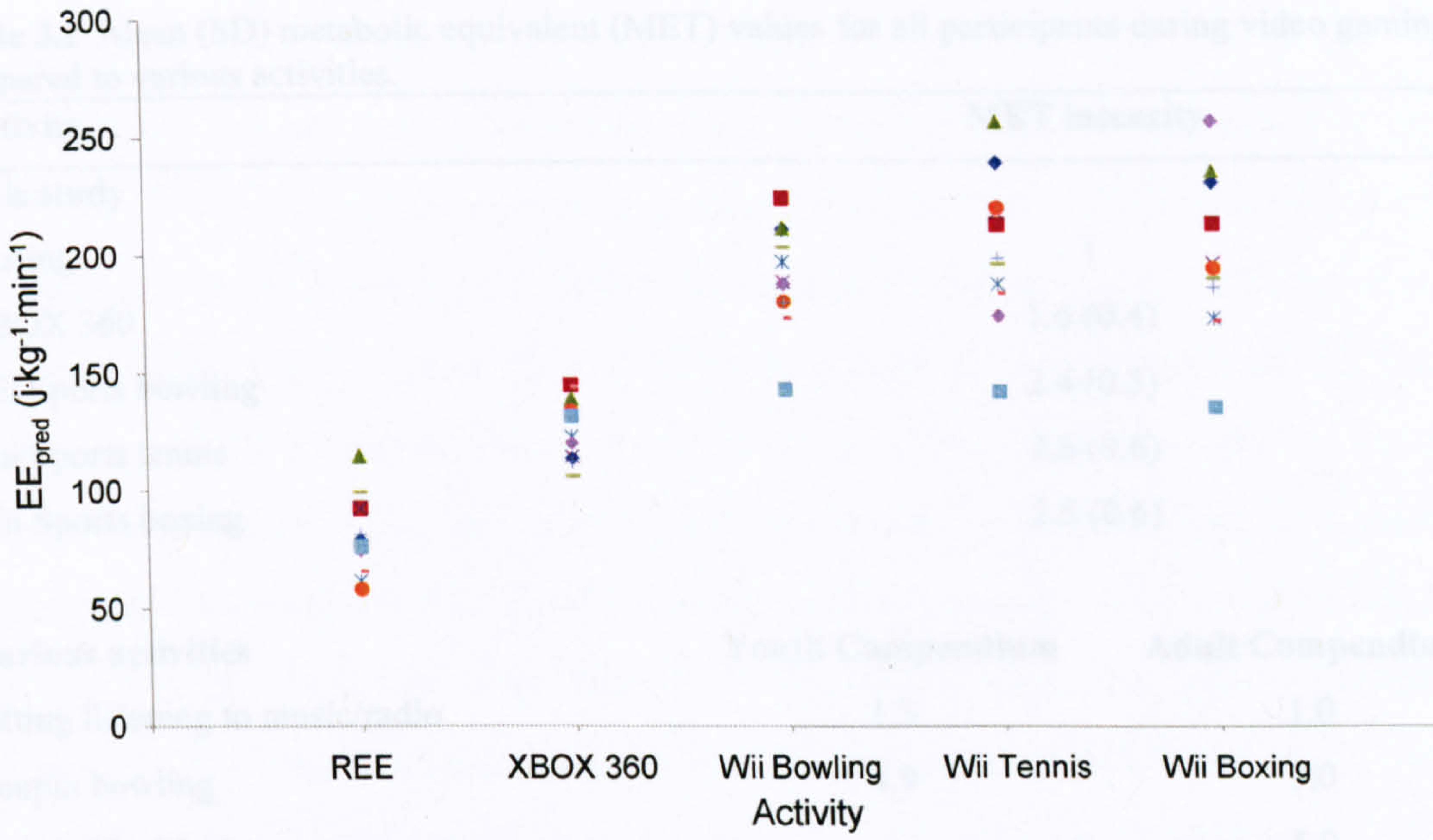

Figure 3.1 Participants' mean resting energy expenditure (REE) and predicted energy expenditure (EE_{pred}) when playing video games.

Table 3.2 compares the group MET intensities of the activities in this study with those reported for various sports and activities, as stated in the Compendium of Physical Activities for Youth (Ridley et al., 2008) and Adults (Ainsworth et al., 2000). All video games elicited light intensity activity (< 3 METs) and comparisons suggest more energy is used when actually bowling, boxing or playing tennis than when playing the Wii versions of these sports.

Table 3.2 Mean (SD) metabolic equivalent (MET) values for all participants during video gaming compared to various activities.

Activity	MET intensity	
This study		
Resting	1	
XBOX 360	1.6 (0.4)	
Wii Sports bowling	2.4 (0.5)	
Wii Sports tennis	2.6 (0.6)	
Wii Sports boxing	2.5 (0.6)	
Various activities	**Youth Compendium**	**Adult Compendium**
Sitting listening to music/radio	1.3	1.0
Tenpin bowling	4.9	3.0
Tennis (doubles)	-	5.0
Boxing (punch bag)	-	6.0
Boxing (sparring)	-	9.0

Values for various activities were taken from the Compendium of Physical Activities for Youth (Ridley et al., 2008) and Adults (Ainsworth et al., 2000). Where a dash is presented (-) the MET value in the Youth Compendium is either represented as the Adult Compendium value or is unavailable.

3.4 Discussion

The promotion of PA to children and adolescents is a public health priority (Biddle et al., 1998). Reducing the time young people spend sedentary may benefit metabolic health (Ekelund et al., 2007) and prevent excessive weight gain in childhood and adolescence (Laurson et al., 2008; Rey-Lopez et al., 2008). Children and adolescents spend potentially large amounts of their free time playing video games in a sedentary manner (Woodward and Gridina, 2000; Pratchett, 2005; Marshall et al., 2006), and are reported to resist relinquishing screen-based activities (Faith et al., 2001; Wilson, 2007). A tool that permits valued screen time whilst promoting PA is an active video game. If the time spent playing sedentary video games was converted to playing active equivalents then video games have the potential to increase regular PA and EE in young people. The aim of this study was to investigate the energetic demands of three active video games in adolescents compared to a sedentary video game.

Sedentary video gaming and active video gaming on Wii Sports bowling, tennis and boxing significantly increased EE_{pred} compared to directly measured REE in boys and girls aged 13 to 15 years. An elevated energy cost over resting values for sedentary video gaming has previously been observed in studies directly measuring $\dot{V}O_2$ (Wang and Perry, 2006; Lanningham-Foster et al., 2006). In these studies, increased EE was attributable to greater oxygen delivery to muscle tissue in the contracting muscles. In the present study, EE_{pred} from the IDEEA was greater as it detected body movements of the trunk and lower limbs. These findings support the suggestion that in associations with PA and health, sedentary video gaming should be isolated from TV viewing and seated rest (Marshall et al., 2004), during which skeletal muscle fibers are relaxed, virtually inactive and use little energy. Compared to rest, the higher energy cost of active video gaming is unsurprising, as it stimulates greater body movement and muscle contraction. This fundamental principle of exercise physiology also explains why the predicted energy cost of active gaming was significantly greater than that during sedentary video gaming, a trend previously observed (Lanningham-Foster et al., 2006; Maddison et al., 2007).

Wii Sports bowling, tennis and boxing were classified as light intensity activities, which is similar to the active video games Nicktoons Movin', Groove and AntiGrav on the Sony EyeToy (Lanningham-Foster et al., 2006; Maddison et al., 2007). In contrast, games such as Homerun, Knockout and Cascade on the Sony EyeToy, and Dance UK on the PS2 have been reported to elicit moderate PA intensities (Maddison et al., 2007). Thus, only certain active video games are sufficiently intense to contribute towards the recommended amount of daily PA for young people. The variability in PA intensity across games is likely due to the type and magnitude of body movements stimulated during play. For example, the Wii Sports games primarily encouraged movement of the arms and trunk, whereas dance games stimulate movement of the legs and hence larger muscle groups that would expend energy at a higher rate. However, no empirical research has currently assessed the specific contribution of different body movements to EE during active gaming. In appreciation of the active video games commercially available, the predominant body motions to assess would be total body movement, which can be measured using motion sensors on the hip, and upper limb movements, which can be measured using motion sensors on the wrist. This would allow evidence-based conclusions to be made as to why certain games elicit greater physiological responses.

Each Wii Sports game significantly increased EE above rest and sedentary video gaming, though less energy appeared to be used compared to participation in authentic bowling, tennis and boxing. To succeed on Wii Sports it was not essential to produce body movements common to authentic play of the sports. For example, during bowling, tennis and boxing, the onscreen character automatically moved down the alley, to the point of ball contact, or away from and to the opponent, respectively. Thus, these features allowed the participant to expend less energy during active video gaming, indicating that active video games are not as costly in terms of EE as actual play of the sport. Nevertheless, the active video games stimulated positive activity behaviours with adolescents on their feet and at times moving the upper and lower body in all directions while performing basic movement skills not evident during sedentary video gaming. Given the rising prevalence of overweight and obesity (Reilly and Dorosty, 1999; Chinn and Rona, 2001; Stratton et al., 2007), and age-related decline in PA throughout adolescence (Biddle et al., 2004b; Strong et al., 2005), an increase in light intensity PA through active video gaming should be encouraged over sedentary video gaming in video game players. This is supported by evidence that increased total PA can promote positive metabolic health in youth (Ekelund et al., 2007), and increased NEAT may be pivotal in EE and weight gain regulation (Levine, 2007). If a portion of video game time is converted from sedentary to active, and combined with PA outside of the home away from the screen, a balanced and varied programme of activity could be created for young people to regularly participate in.

The gender main effect for EE approached statistical significance, with boys EE_{pred} greater than girls, especially for active video gaming. This suggests that boys performed more movements detectable by the IDEEA system, namely of the torso and lower body. Given the active video games primarily encouraged upper limb movement, this suggests that despite participants being sport competent, boys performed more movements not necessarily required to play the games. Active video games may therefore encourage greater movement in boys with additional EE advantages. This gender difference in PA and EE_{pred} is be congruent with research indicating gender as a key determinant of youth PA, with boys more active than girls (Sallis et al., 2000; Biddle et al., 2004b; Van der Horst et al., 2007).

Alternatively, the observed gender difference may relate to participant experience of video games and the sports simulated, or technique and success during game play. For example, though participants had not previously used the Wii, and boys and girls, respectively, spent a similar ($p > 0.05$) amount of time on Wii Sports bowling (mean (SD) 11.3 (2.2) vs. 11.4 (3.1) min), tennis (7.8 (0.8) vs. 8.6 (3.5) min) and boxing (9.3 (0.5) vs. 9.6 (2.2) min) during familiarisation, boys self-reported spending more time playing video games compared to girls, consistent with previous research (Marshall et al., 2006). Furthermore, boys self-reported to play more sport-based video games compared to girls. When participants were asked to play a new sports-based video game, boys' greater experience of video gaming, especially that sport-based, may have encouraged greater body movement and EE_{pred} due to greater familiarity with this type of activity.

Conversely, greater familiarity may have reduced boys' playing anxiety and improved their ability to concentrate and play with success (Sell et al., 2008). For Wii Sports tennis, which exhibited the greatest gender difference in EE_{pred}, this theory may be applicable, as boys won more games compared to girls (respective mean (SD) 2.2 (1.0) vs. 1.2 (0.4) games, $p = 0.04$), lost fewer games (3.5 (1.0) vs. 5.8 (1.6) games, $p = 0.02$) and played fewer games overall (5.7 (1.0) vs. 7.0 (1.2) games, $p = 0.081$). Greater success would result in boys progressing to higher difficulty levels in the game, which may be associated with increased game durations due to tougher CPU opponents. By playing fewer games boys would also spend less time waiting for a new game to load, and these combined factors may have encouraged more continuous playing time, body movements and EE_{pred}. Sell et al. (2008) support this explanation, as twelve young adults experienced with a dance simulation game were found to play at a higher difficulty level than seven inexperienced young adults during 30 min of play on a dance simulation game. This was associated with more continuous game play, increased overall body movements, and significantly greater EE and HR in the experienced players (Sell et al., 2008). In the present study progression to higher difficulty levels may have been due to greater experience of authentic tennis, though information on previous participation in, and enjoyment of tennis or other sports was not obtained. The observed gender difference may also be due to greater motivation in boys to play actively independent of video game or sporting experience. Cardiorespiratory fitness may have contributed to the gender difference, though this was not assessed. Potentially lower fitness in girls compared to boys may have led to greater fatigue and fewer movements of the legs and torso during gaming, resulting in lower EE_{pred}.

Despite detecting statistically significant differences in EE_{pred}, the study was further limited by the small convenience sample. Thus, the results are only applicable to lean, sports competent 13 to 15 year olds and to the Wii Sports video game, which encourages more activity than other Wii games. A larger sample or youth of different ages may exhibit different responses to the activities investigated. The study failed to directly measure EE ($\dot{V}O_2$) during gaming due to technical difficulties with the portable indirect calorimetry system, with data from the IDEEA used. Though the IDEEA accurately estimates free living and physical activity energy expenditure (PAEE) (Zhang et al., 2004), and has been used as a criterion measure in a method comparison study (Welk et al., 2007), the system is not sensitive enough to detect arm movements. Therefore, EE may have been underestimated during sedentary and active video gaming, as small and gross arm movements were required, respectively, with additional energetic advantages over rest, and over sedentary gaming for active gaming, potentially masked.

This study was laboratory-based and may not have replicated conditions in the home. However, participants followed instructions provided for home use, and energetic responses are unlikely to be significantly different in a home-based study. The results are only indicative of the responses to active gaming over a short-period on one occasion. However, the 15 min of play per game was not burdening for participants and was similar to the time provided in studies investigating the energy cost of activities in youth (Harrel et al., 2005; Lanningham-Foster et al., 2006; Maddison et al., 2007). Longitudinal studies evaluating whether training or learning effects associated with repeated active video gaming influence physiological responses are warranted to inform the long-term ability of these devices to increase PA and EE. The order of gaming during trials was not randomised due to limited participant availability and a need for the most efficient experimental design. It is possible there may have been an effect (e.g. fatiguing) of a previous activity or activities on the body movements and EE_{pred} during subsequent activities. However, the 5-min seated rest period between activities, which is similar if not greater than provided in related investigations (Lanningham-Foster et al., 2006; Maddison et al., 2007), would likely eliminate any significant effect of previous activities. The effect of a previous activity was also protected against by activities being performed in an order perceived progressively intense. The intermittent nature of gaming on Wii Sports, inclusive of transient rest periods, would further reduce potential fatiguing effects. Finally, comparisons between the MET intensities of Wii Sports and authentic versions of the sports were not based on data from the same subjects in a repeated measurements design. Though this would strengthen the conclusions presented, such repeated measurements were not feasible due to limited resources and participant availability, and comparisons were made to previous energy costs in youth where possible.

3.5 Conclusion and future research

Active video games significantly increased EE compared to sedentary video games. The magnitude of increase in EE for the active video games was insufficient however to contribute towards recommendations for daily PA in young people, and were less than those previously observed for authentic sports. Nevertheless, compared to sedentary video gaming, active video games discouraged sedentary time and stimulated positive activity behaviours. Given the potential health benefits of increased total PA and NEAT in young people, converting screen time from sedentary to active should be encouraged in video game players. A non-significant trend for greater EE in boys than girls was observed during active gaming. This may be due to boys' greater motivation to participate actively, or boys playing at a higher level of difficulty compared to girls, which encouraged more continuous playing time. From an energy balance perspective, boys may benefit more so than girls from playing active video games.

Research assessing the energy cost of gaming on Wii Sports with directly measured $\dot{V}O_2$ is warranted to confirm these findings. No empirical research has currently assessed the specific contribution of different body movements to EE during active video gaming, which is important due to their non-ambulatory nature. The present and related studies suggest that predominant motions encouraged and to be assessed during active video gaming are of the upper limbs and total body. Measurement of these motions can be achieved through the use of accelerometers placed on the wrist and hip, and will allow evidence-based conclusions to be made as to why games stimulate different increases in activity levels and the associated physiological costs. Moreover, this would provide information on the accuracy of multi-site activity monitoring for predicting EE in young people.

3.6 Acknowledgements

This work was funded by Cake, marketing arm of Nintendo UK.

Chapter 4

The Contribution of Upper Limb and Total Body Movement to Adolescents' Energy Expenditure whilst Playing Non-Ambulatory Active Video Games

The contribution of upper limb and total body movement to adolescents' energy expenditure whilst playing non-ambulatory active video games

The main outcomes of this study have been published in the European Journal of Applied Physiology (Graves, L. E. F., Ridgers, N. D., Stratton, G. (2008). The contribution of upper limb and total body movement to adolescents' energy expenditure whilst playing Nintendo Wii. *European Journal of Applied Physiology,* **104(4),** 617-623) (please see Appendix 2).

4.1 Introduction

Increasing PA and reducing the time spent sedentary are important for cardiovascular and metabolic health in childhood and adolescence (Andersen et al., 2006; Ekelund et al., 2007). Maintaining a favourable disease risk factor profile in youth is important as risk factors such as adverse levels of serum lipids and lipoproteins, and excess adiposity, are related to health problems such as dyslipidemia, obesity, hypertension, some cancers, arthritis and cardiovascular disease in adulthood (Nicklas et al., 2002; Must et al., 1992; Eisenmann, 2004). Strategies for achieving increased PA and reduced sedentary time have been implemented through school- and home-based interventions (Jago and Baranowski, 2004; Robinson, 1999), highlighting the need to tackle low levels of PA in all the environments young people interact with. The promotion of PA in the home is probably important as contemporary youth spend a significant portion of their time within this setting in sedentary screen-based behaviours (Biddle et al., 2003; Pratchett, 2005; Marshall et al., 2006). A greater level of environmental risk perceived by parents (Spanier et al., 2006; Biddle et al., 1998) suggests that providing children and adolescents with opportunities to be physically active indoors may be particularly appealing. Active video games have the potential for increasing opportunities for, and the promotion of, PA in the home.

Active video games stimulate PA through total body movement via dance mats (DDR) or camera technology (Sony EyeToy), or upper limb movement via the use of wireless hand-held controllers (Nintendo Wii). Compared to rest and sedentary video games, active video games are reported to significantly increase children and adolescents' total body movement, as measured by a hip-mounted accelerometer (Maddison et al., 2007), and EE (Lanningham-Foster et al., 2006; Maddison et al., 2007, Graves et al., 2007). However, no empirical research has documented the contribution of upper limb or total body movement to EE during active video gaming. Upper limb movements appear to provide a substantial contribution to overall PA and its related EE during play on some active video games, similar to the total PA of daily living (Kumahara et al., 2004). Thus, the quantification of upper limb and total body movement seems important in order to make evidence-based conclusions as to why active video games stimulate different increases in activity levels and the associated physiological costs. Given that upper limb movements are poorly captured by hip-mounted accelerometers, multi-site activity monitoring can address this research question (Trost et al., 2005; Rowlands, 2007). Multi-site activity monitoring will also provide information on the value of assessing upper limb movements in addition to total body, for the accurate prediction of EE in young people during these non-ambulatory activities, which has been suggested as an area for future research (Trost et al., 2005).

For activities of daily living and treadmill locomotion, research in adults suggests that prediction equations including accelerometer counts from a wrist and hip improve the variance explained in EE by 1.5 to 2.6% compared to counts from the hip alone (Swartz et al., 2000; Kumahara et al., 2004). However, the improvements in explanatory power were consistently concluded insufficient to warrant the associated cost of the additional monitor and time required to analyse the data (Swartz et al., 2000), providing little support for the use of multiple accelerometers to predict PA and EE in adults. To date, no published study has investigated this combined measurement approach in young people. Compared to adults, children and adolescents engage in a greater variety of movement (Eston et al., 1998). Moreover, sporadic and deliberate movements of the arms are likely encouraged by the activities children and adolescents typically engage in, such as creative play (e.g. playing a musical instrument, playing with toys, arts and crafts) and unorganised (e.g. skipping, playing catch, general playground activities, swimming, ball and racket sports) and organised (competitions and practices for such sports) active play (Eston et al., 1998; Vandewater et al., 2006). Through these activities it is logical to suggest that the contribution of upper limb movements to total EE will be greater in young people compared to adults. Investigating whether the additional assessment of upper limb movements through accelerometry can improve predictions of EE in youth over sole monitoring at the hip is therefore important. The aim of this study was to examine the contribution of upper limb and total body movement to adolescents' EE whilst playing active video games on the Nintendo Wii, which predominantly encourage upper body movement.

4.2 Method

4.2.1 Participants and setting

Six girls and seven boys aged 11 to 17 years participated in the present study. All participants were recruited via word of mouth and though none owned a Nintendo Wii at the time of testing, all stated they had previously used the console. Data from a video gaming experience questionnaire (please see Appendix 1) indicated that male and female participants played video games for a mean (SD) 5.7 (2.6) and 2.0 (1.5) $h \cdot wk^{-1}$, respectively. Parents and participants gave written informed consent and assent respectively. The study was approved by the University ethics committee and all measures were taken at RISES.

4.2.2 Procedure

4.2.2.1 Anthropometry

Stature and body mass were measured using the same equipment and standard anthropometric techniques as study one. Body mass index (BMI) was calculated as mass divided by stature ($kg \cdot m^{-2}$).

4.2.2.2 Familiarisation

On separate days to experimental trials, participants were familiarised with the sedentary video game PGR3 and the active video games of bowling, tennis and boxing on Wii Sports. For details of these video games please see Chapter 4. For PGR3, seated participants used the wireless handheld controller to race against CPU opponents on a single player race mode for 10 min. For Wii Sports, standing participants practised for 10 min on each of the training modes of bowling, tennis and boxing. The order of gaming was randomised. All participants were right handed and the active video games were set up to accommodate this. The participant's dominant hand was deemed the hand they wrote with. During familiarisation participants wore an Actiheart sensor (Cambridge Neurotechnology, Cambridge, UK), four ActiGraph accelerometers (GT1M, ActiGraph LLC, Pensacola, FL, USA) and a portable MetaMax 3B system with an accompanying facemask.

4.2.2.3 Resting measurements and experimental trial

Each participant performed one experimental trial. Participants were fitted with an Actiheart sensor, four ActiGraph accelerometers, and, a portable MetaMax 3B system and accompanying facemask. Following at least 2 h of fasting and 5 min of supine rest, resting $\dot{V}O_2$ and resting heart rate (RHR) were measured for 6 min in a quiet darkened room (Unnithan et al., 2006; Maddison et al., 2007; Graves et al., 2007) by the MetaMax 3B and Actiheart HR sensor, respectively. In a randomised order, participants played for 15 min on each video game (PGR3, Wii Sports bowling, tennis, boxing) with 5 min of seated rest between each. The video games were played in a manner identical to that described in Chapter 4. Once a race or game was completed the event was restarted and this continued for the 15 min. Total game playing time for each participant was 60 min.

4.2.3 Instrumentation

4.2.3.1 Physical activity

Uniaxial accelerometers (ActiGraph GT1M, ActiGraph LLC, Pensacola, FL, USA) measured PA during the experimental trial. The ActiGraph weighs 27 g and when worn on the hip, which is the typical location for placement, the sensitive axis is orientated to measure acceleration in the vertical plane (ActiGraph, 2005; Rowlands, 2007). ActiGraph has a band pass filtering range of 0.21 to 2.28 Hz, a sampling frequency of 30 Hz, and an amplitude range of ± 2.13 g. It is the most widely used uniaxial accelerometer (Rowlands, 2007) and has acceptable validity and reliability for use in paediatric studies (Trost et al., 1998; Ekelund et al., 2001). In addition to firmly securing an ActiGraph on the midaxillary line of the right and left hip via an adjustable nylon strap, a unit was secured on each forearm proximally from the wrist joint using smaller straps. Monitors did not restrict participants' movement during the trial. ActiGraph were set to record the frequency, duration and intensity of PA in 5-s epochs throughout the trial. Data were downloaded after each trial using manufacturer software (Version 2.0.0, ActiGraph LLC, Pensacola, FL, USA) and raw data were exported in 5-s epochs for analysis on a personal computer. The same ActiGraph units were used at each location for all participants.

4.2.3.2 Heart rate

An Actiheart sensor measured HR during the resting protocol and experimental trial. The Actiheart is a one-piece combined HR and movement sensor that has the primary purpose of predicting PAEE from measurements of acceleration and HR (Brage et al., 2005). The sensor has a mass of 8 g and consists of two components, one 7 mm thick with a diameter of 33 mm, the other 5 x 11 x 22 mm^3, which are connected by a thin and flexible wire 100 mm in length (Brage et al., 2005). The HR sensor records HR, ECG waveforms and the variability of the interbeat interval. The sensor was found to provide reliable and valid measures of HR in a simulation study and in comparisons with ECG monitoring at rest and during treadmill walking and running in nine adults aged 24 to 47 years (Brage et al., 2005). The Actiheart was also found to be valid for predicting PAEE against indirect calorimetry during treadmill walking and running in thirty-nine adolescents (mean age (SD) 13.2 (0.3) years) (Corder et al., 2005).

In the present study the Actiheart was attached to participants via two ECG electrodes (52 x 54 mm; AgC1, Red Dot 2570, 3M). The medial electrode was attached on the skin at the base of the sternum, with the lateral electrode horizontally to the left side. The Actiheart wire was straight but not taut. Prior to electrode attachment the skin was lightly prepared by participants based on manufacturer guidelines (Actiheart Guide to Getting Started users manual). Participants used a towel to rub the skin with enough vigour to remove the top layer. Normal redness was apparent but of no concern, and this process ensured sufficient detection of R wave signals by the sensor. Before each measurement period a manufacturer recommended signal test was conducted to ensure the HR signal was adequately detected. ECG waveforms were recorded for between 30 to 60 s, and if detection was adequate, the monitor was set to record HR in the short-term recording mode continuously over 15-s epochs. Data were downloaded after each measurement period using a reader interface unit and processed using Actiheart software (Version 2.132, Cambridge Neurotechnology Ltd, Cambridge, UK). Raw data for each measurement period were exported in 15-s epochs and analysed on a personal computer. The same Actiheart unit was used for all participants. Heart rate data for one participant (male) in all video games was lost due to sensor failure.

4.2.3.3 Gas analysis

Expired air was measured during the resting protocol and experimental trial by a portable MetaMax 3B. For system details and methods of its use please see Chapter 4. Throughout resting and trial periods $\dot{V}O_2$ data were averaged over 15-s epochs. Raw data for each measurement period were exported from the manufacturer software in 15-s epochs and analysed on a personal computer. Monitoring problems resulted in a loss of $\dot{V}O_2$ data for one participant (male) for sedentary video gaming and a second participant for Wii Sports tennis and boxing (female).

4.2.4 Data handling and statistical analyses

Mean resting $\dot{V}O_2$ ($l \cdot min^{-1}$) and RHR ($beats \cdot min^{-1}$) were calculated by averaging the last 2.5 min of data during the 6-min resting phase (Unnithan et al., 2006; Maddison et al., 2007; Graves et al., 2007). For each activity within the trial, mean $\dot{V}O_2$, HR and activity from each accelerometer (CPM) were calculated using all data during the 15 min of gaming. Mean $\dot{V}O_2$ values at rest and for each activity were converted into EE ($J \cdot kg^{-1} \cdot min^{-1}$) using the constants of 1 l O_2 = 4.9 kcal and 1 kcal = 4.18 kJ (McArdle et al., 1991) and participant body mass. Participant-specific METs were calculated for each activity by dividing the mean $\dot{V}O_2$ of the activity by resting $\dot{V}O_2$. With regard to missing data, participants were only removed from any analysis that included the dependent variable they were missing.

Independent samples t-tests or Mann-Whitney tests were used to compare between genders descriptive data. Test choice was dependent on the normality of data distribution by gender, with non-parametric analysis conducted on variables with significant Shapiro-Wilk test results. Oxygen consumption, EE and HR data were analysed using a two-group mixed-design ANOVA with *gender* (*boys, girls*) as the between-groups factor and *activity* (*rest, sedentary video game, Wii bowling, Wii tennis, Wii boxing*) as the within-groups factor (Field, 2000). The same two-group mixed ANOVA were run on accelerometer count data from each hip and wrist, but the within-groups factor *activity* had only four levels (*sedentary video game, Wii bowling, Wii tennis, Wii boxing*). If Mauchly's test indicated lack of sphericity and the sphericity estimate was less than 0.75, the Greenhouse-Geisser epsilon was used to correct the analysis, but when the sphericity estimate was greater than 0.75 the Huynh-Feldt epsilon correction was used (Field, 2000). In the presence of a significant main effect for gender or activity, post hoc pairwise comparisons with a Bonferroni correction for type I error control were investigated (Field, 2000). If the gender x activity interaction was significant, independent t-tests were performed amongst pairwise group means with a Bonferroni correction for type I error control (Atkinson, 2002).

Linear regression was used to predict EE from accelerometer counts (left hip, right hip, left wrist, right wrist) and HR. Prediction of EE from a combination of accelerometer counts and HR was completed by multiple linear regressions with forced entry of predictors. Collinearity diagnostics indicated that multicollinearity between predictors was not serious. The variance inflation factor (VIF) values were below 3.0 and the tolerance statistics were greater than 0.3 (Field, 2000). SPSS v14 (SPSS Inc, Chicago, USA) was used for statistical analysis with statistical significance set at $p \leq 0.05$. The results are expressed as means and standard deviations (SD).

4.3 Results

4.3.1 Descriptive analyses

Table 4.1 presents descriptive characteristics of the participants. Stature for boys was significantly greater than girls ($p = 0.036$).

Table 4.1 Mean (SD) descriptive characteristics of participants.

	All (n = 13)	Boys (n = 7)	Girls (n = 6)
Age (years)	15.1 (1.4)	15.0 (1.7)	15.2 (1.2)
Body mass (kg)	62.8 (9.5)	67.0 (10.4)	57.8 (5.8)
Stature (m)	1.69 (0.13)	1.76 (0.12)	1.62 (0.09) *
BMI ($kg \cdot m^{-2}$)	22.0 (2.6)	21.8 (3.1)	22.2 (2.0)

* $p = 0.036$ (different from Boys)
BMI = body mass index.

4.3.2 Main analyses

Group values for activity data are presented in Table 4.2 for all video games. The two-group mixed-design ANOVA resulted in a significant main effect for activity for accelerometer counts from the right and left wrist ($F = 57.68$ and 34.13, respectively, $p < 0.001$). Compared to the sedentary video game, right wrist counts were greater for all Wii Sports games and left wrist counts were greater for tennis and boxing ($p < 0.05$). Left wrist counts were greater for boxing compared to bowling and tennis ($p < 0.01$). Greater right wrist counts for tennis compared to bowling approached statistical significance ($p = 0.061$). There was no main effect for activity for right or left hip count data ($F = 3.54$ and 2.73, respectively, $p > 0.05$). There was no significant main effect for gender or gender x activity interaction for any accelerometer count variable ($p > 0.05$). Right wrist counts were greater than left wrist for tennis and bowling, and mean wrist counts were greater than mean hip for all video games ($p < 0.05$; Wilcoxon tests).

Table 4.2 Mean (SD) activity counts (CPM) by accelerometer location for each video game.

	Right hip	Left hip	Right wrist	Left wrist
XBOX 360	7 (10)	4 (5)	117 (96) *	174 (193) **
Wii Sports bowling	153 (173)	124 (132)	9648 (2491)	2454 (3188) ***
Wii Sports tennis	123 (171)	151 (222)	12348 (4137)	3064 (2859) ***
Wii Sports boxing	380 (611)	386 (657)	11401 (3813)	10338 (4114) ****

* $p < 0.05$ (different from bowling, tennis and boxing)
** $p < 0.05$ (different from tennis and boxing)
*** $p < 0.001$ (different from right wrist)
**** $p < 0.01$ (different from tennis and bowling)

The relationship between measured EE and activity counts from the hip-worn accelerometers were highly significant for all active video games ($r = 0.68$ to 0.94; $p \leq 0.02$). Activity counts from the left wrist for Wii Sports tennis and boxing ($r = 0.71$ and 0.74, respectively; $p \leq 0.01$) and the right wrist for boxing ($r = 0.59$; $p = 0.023$) were significantly correlated with EE. Of the single measures right hip activity counts for Wii Sports bowling (62%) and boxing (88%), and left hip activity for tennis (53%) explained most of the variance in EE, as shown in Table 4.3. The least accurate predictor of EE for all video games was HR ($R^2 \leq 0.04$). Multiple regression analysis indicated that each active video game had two, two-measure prediction equations that most accurately accounted for variations in EE (Table 4.3). The addition of a second measure improved the explained variance in EE for Wii Sports bowling, tennis and boxing by 18%, 11% and 7%, respectively.

Table 4.3 Prediction equations for energy expenditure (EE; $J \cdot kg^{-1} \cdot min^{-1}$) for the most accurate single- and two-measure models during active video gaming. Predictors include heart rate (HR) and activity data from an ActiGraph on the right hip (RH), left hip (LH), right wrist (RW), and left wrist (LW).

Model	Prediction equations	R^2	SEE
Bowling			
RH	EE = 2.257 counts + 153.346	0.62	26.53
HR + LH	EE = -1.308 HR + 3.857 counts + 277.509	0.81	19.83
LH + LW	EE = 2.866 counts + 0.070 counts + 138.388	0.80	20.45
Tennis			
LH	EE = 2.121 counts + 173.779	0.53	38.88
HR + LW	EE = 1.348 HR + 0.180 counts + 10.199	0.64	36.16
LH + LW	EE = 1.363 counts + 0.96 counts + 158.816	0.64	35.79
Boxing			
RH	EE = 2.164 counts + 194.131	0.88	43.98
HR + RH	EE = -1.643 HR + 2.510 counts + 412.197	0.98	20.30
RH + RW	EE = 2.913 counts – 0.157 counts + 324.091	0.95	28.78

SEE = standard error of the estimate.

Group values for $\dot{V}O_2$, EE and HR are presented in Table 4.4 for all activities. Figures 4.1 and 4.2 provide an indication of the variability in EE and HR, respectively, across participants at rest and during video gaming. The two-group mixed-design ANOVA resulted in a significant main effect for activity for $\dot{V}O_2$, EE and HR ($F = 20.93$, 29.12 and 93.28, respectively, $p < 0.001$). Oxygen consumption, EE and HR for all video games was greater than resting values ($p < 0.05$) and greater for all Wii Sports games than sedentary video gaming ($p < 0.05$). Heart rate for Wii Sports boxing was greater than bowling and tennis ($p < 0.01$). A significant gender main effect for HR was observed ($F = 10.11$, $p = 0.011$), with girls' HR greater than boys. There were no main effects for gender for $\dot{V}O_2$ or EE ($F = 0.62$ and 0.06, respectively, $p > 0.05$). There was a significant gender x activity interaction for HR ($F = 4.56$, $p = 0.021$). Independent t-tests indicated girls' HR was significantly greater for all active video games compared to boys (respective HR: bowling 114.7 (12.6) vs. 91.8 (12.1) $beats \cdot min^{-1}$; tennis 118.2 (10.7) vs. 95.8 (9.5) $beats \cdot min^{-1}$; boxing 155.1 (18.1) vs. 118.2 (13.2) $beats \cdot min^{-1}$, $p_{corrected} < 0.05$), and approached statistical significance for sedentary video gaming (91.9 (8.5) vs. 79.2 (11.3) $beats \cdot min^{-1}$, $p_{corrected} = 0.068$). There was no gender x activity interaction for $\dot{V}O_2$ or EE ($F = 0.28$ and 0.66, respectively, $p > 0.05$). The group MET intensities of sedentary video gaming, and Wii Sports bowling, tennis and boxing were 1.4 (0.3), 2.2 (0.4), 2.3 (0.6) and 3.0 (1.0) METs, respectively.

Table 4.4 Mean (SD) oxygen consumption ($\dot{V}O_2$), energy expenditure (EE) and heart rate (HR) at rest and for each video game for all participants.

	$\dot{V}O_2$ (l·min^{-1})	EE (J·kg^{-1}·min^{-1})	HR (beats·min^{-1})
Rest	0.25 (0.06) *	83.6 (16.0) *	71.8 (12.1) *
XBOX 360	0.35 (0.07) *	115.4 (19.1) *	85.0 (11.7) *
Wii Sports bowling	0.55 (0.17)	180.0 (37.7)	100.7 (15.0)
Wii Sports tennis	0.57 (0.16)	189.0 (38.5)	105.1 (14.5)
Wii Sports boxing	0.75 (0.33)	242.5 (81.7)	134.2 (24.1) **

* $p < 0.05$ (different from bowling, tennis and boxing)
** $p < 0.05$ (different from bowling and tennis)

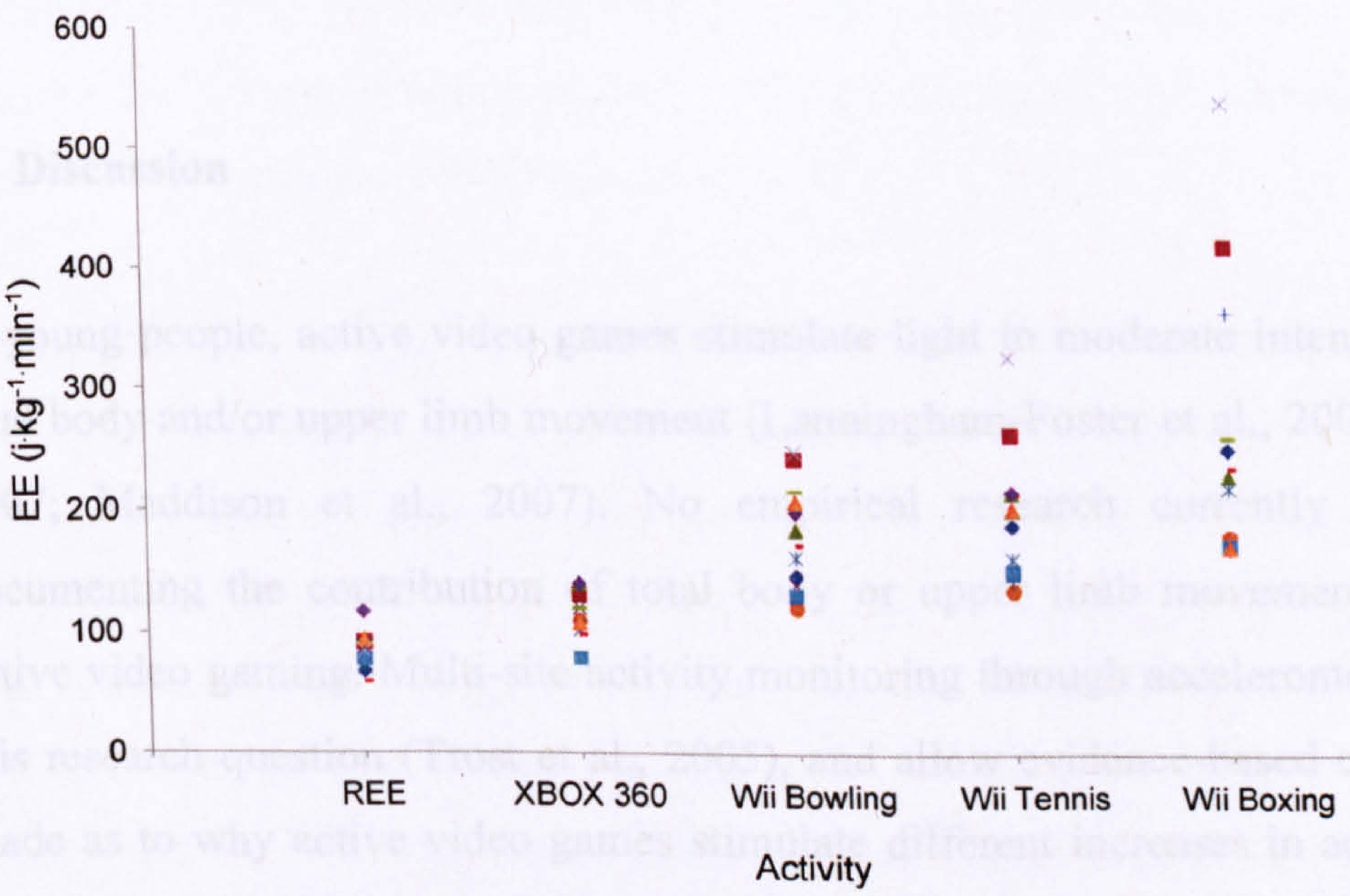

Figure 4.1 Variability in energy expenditure (EE) for participants at rest and during play on all video games.

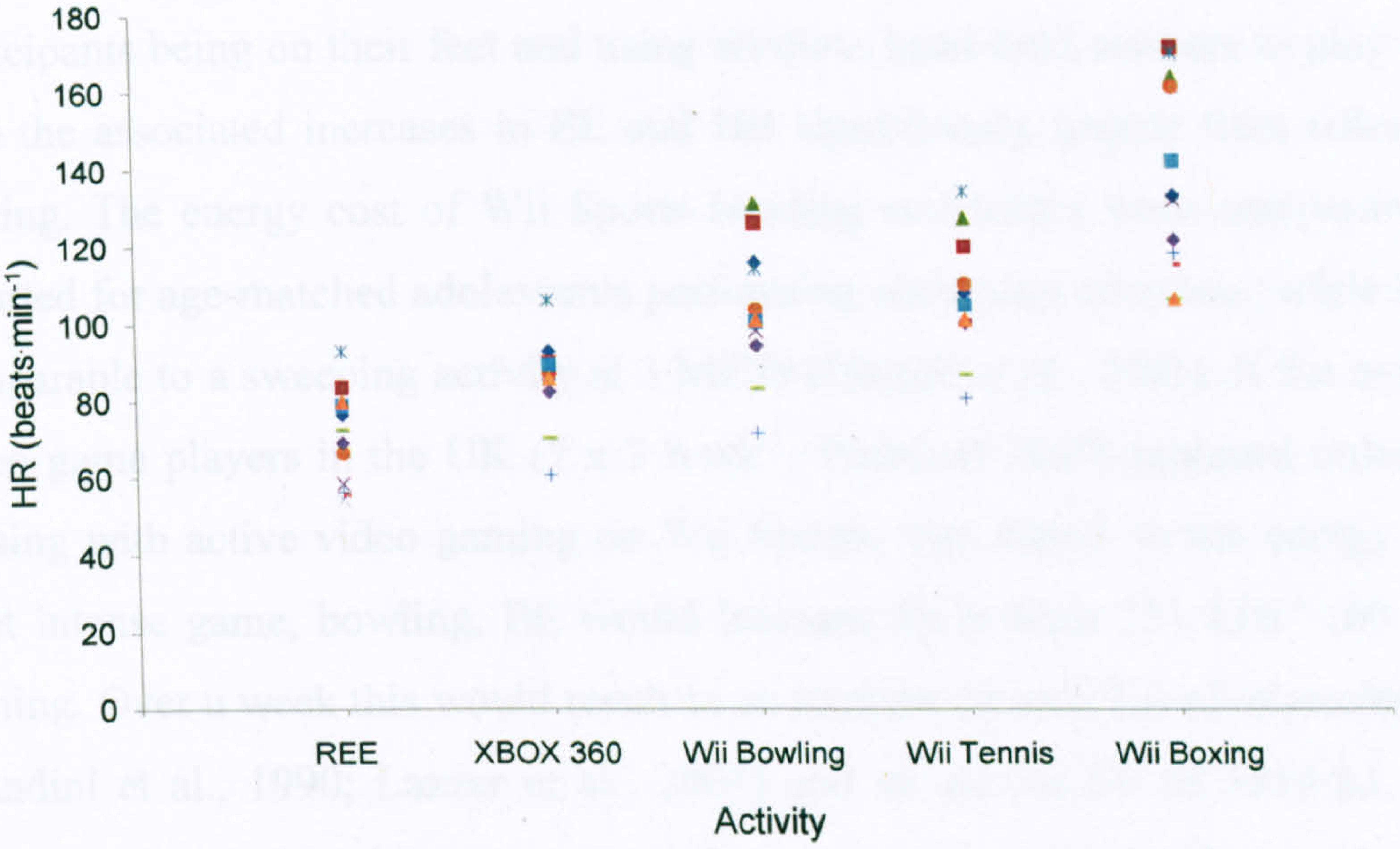

Figure 4.2 Variability in heart rate (HR) for participants at rest and during play on all video games.

4.4 Discussion

In young people, active video games stimulate light to moderate intensity PA through total body and/or upper limb movement (Lanningham-Foster et al., 2006; Graves et al., 2007; Maddison et al., 2007). No empirical research currently exists however documenting the contribution of total body or upper limb movements to EE during active video gaming. Multi-site activity monitoring through accelerometers can address this research question (Trost et al., 2005), and allow evidence-based conclusions to be made as to why active video games stimulate different increases in activity levels and the associated physiological costs. Moreover, this measurement approach will provide recommended data on whether the prediction of EE in young people during non-ambulatory activities can be improved using combined sensing technologies compared to single measures, such as activity monitoring at the hip (Trost et al., 2005). The aim of this study was to examine the contribution of upper limb and total body movement to adolescents' EE whilst playing active video games on the Nintendo Wii.

Compared to sedentary video gaming, active video gaming on Wii Sports increased total body and upper limb movement in adolescent boys and girls. This was a result of participants being on their feet and using wireless hand-held remotes to play the games, with the associated increases in EE and HR significantly greater than sedentary video gaming. The energy cost of Wii Sports bowling and tennis were comparable to those reported for age-matched adolescents performing stretching exercises, while boxing was comparable to a sweeping activity at 3 METs (Harrell et al., 2005). If the most frequent video game players in the UK (7 x 2 $h \cdot wk^{-1}$; Pratchett 2005) replaced sedentary video gaming with active video gaming on Wii Sports, then based on the energy cost of the least intense game, bowling, EE would increase by at least 251 $kJ \cdot h^{-1}$ (60 $kcal \cdot h^{-1}$) of gaming. Over a week this would result in an increase in total EE of approximately 4.5% (Bandini et al., 1990; Lazzer et al., 2003) and an excess EE of 3514 kJ, if all other factors such as habitual PA away from the screen and energy intake remained constant. This is a sizeable increase and could, if sustained, contribute to weight management. For example, with water and protein considered, approximately 30,000 kJ of energy is contained in 1 kg of body fat. Therefore, an adolescent could lose 1 kg of fat in approximately 8 weeks with such conversion of video gaming from sedentary to active, if all other factors again remained constant.

During sedentary and active video gaming, activity counts at the wrist (representing upper limb movement) were greater than counts at the hip (representing total body movement). This is comparable to other sitting and standing activities (Kumahara et al. 2004), and was attributable to the format of the video games, with the wireless hand-held controller encouraging upper rather than total body movement. When comparing Wii Sports tennis and bowling, movement of the dominant limb was greater during tennis, with the difference approaching statistical significance. This could be because bowling was self-paced, while tennis was externally-paced requiring interaction with the CPU until a point was won or lost. Given movement of the non-dominant limb and total body did not significantly differ between these games, the increased physiological cost of tennis compared to bowling can be attributed to this increase in dominant limb activity.

A second externally-paced game, Wii Sports boxing, elicited greater EE and significantly greater HR compared to bowling and tennis. Movement of the dominant limb during boxing was comparable to bowling and tennis. However, movement of the non-dominant limb was significantly greater during boxing compared to bowling or tennis. This suggests the increased physiological cost of boxing was due to the game encouraging use of both arms. In addition, total body movement for boxing was more than double that for bowling or tennis, though this increase was non-significant. Consequently, the EE of boxing at 3.0 METs falls within the prescribed range of 3.0 to 6.0 METs for an activity to classified as moderately intense (Freedson et al., 1998). Though this EE just meets the lower boundary for moderate PA, engaging in Wii Sports boxing could theoretically contribute towards the daily PA recommendation in adolescents of 60 min of MVPA (Biddle et al., 1998).

To objectively measure activity-related EE using accelerometers, the recommended site for monitor placement is the right hip (Rowlands, 2007). This is because on the hip the sensitive axis of the accelerometer is orientated to measure acceleration in the vertical plane (Rowlands, 2007), which is the plane in which the majority of daily PA occurs via ambulatory activities (Kumahara et al., 2004). Though the activities investigated in the present study were non-ambulatory, our results support accelerometer placement at this site, as the assessment of total body movement from an accelerometer on the right or left hip had a closer relationship with EE compared to upper body movement. Of the single-measures, HR explained the least variance in EE, with inaccuracies during the low-to-moderate intensity active video games comparable to previous research (Livingstone et al., 2000). A linear relationship between HR and $\dot{V}O_2$ is necessary for the accurate estimation of EE (Ainslie et al., 2003). However, in low intensity activities this relationship can be weakened due to emotional responses such as anxiety and arousal elevating HR without a similar increase in $\dot{V}O_2$, and as such poor prediction of EE through HR monitoring is observed (Livingstone et al., 2000; Sirard and Pate, 2001).

Despite this, results indicated that HR data added with activity data from a hip or wrist substantially improved the explained variance in EE for all games by 10 to 19%. Most notably, HR and right hip activity data explained 98% of the variance in EE during boxing. This supports methods that utilise HR and activity data concurrently to predict EE during PA (Brage et al., 2007; Corder et al., 2005; Corder et al., 2007b). A greater understanding of the ideal accelerometer location is required as this was video game dependant. When wrist activity data were added as a second predictor to hip data, the explained variance in EE for active video gaming improved by 12% on average (range 7 to 18%), which is comparable to the improvements observed for HR and hip activity data. Though activity data was taken from either the right or left, hip and wrist, these results contrast previous research in adults reporting only minor improvements (1.5 to 2.6%) in the variance explained in the EE of a variety of activities, when dominant wrist and right hip activity data were used (Kumahara et al., 2004; Swartz et al., 2000). These substantial improvements in explanatory power provide some support for the additional assessment of upper limb movements in adolescents during non-ambulatory activities such as active video gaming. Given that young people are likely to participate in several non-ambulatory activities during a typical day that encourage activity-related EE from the upper limbs (Eston et al., 1998; Vandewater et al., 2006), further research is warranted to investigate if the observed improvements of multi-site activity monitoring for estimating EE translate into free-living assessments of habitual PA. This could be achieved by simultaneously measuring total EE by the doubly labeled water method, though use of this criterion measure is costly.

No significant main effect or gender x activity interaction was evident for EE or any accelerometer count variable. Similar PA levels, and hence EE, may be due to boys and girls playing at a comparable level of difficulty within each game (Sell et al., 2008). This is supported by non-significant ($p > 0.05$) differences in performance between boys and girls for Wii Sports bowling (respective mean bowling points per game (SD) 150.0 (16.7) vs. 137.1 (25.4)), tennis (games won 3.2 (2.1) vs. 2.0 (2.0), games lost 2.8 (2.0) vs. 5.0 (3.1), games played 6.0 (1.5) vs. 7.0 (1.4)) and boxing (games won 6.0 (1.4) vs. 4.8 (1.3)). In contrast, girls' HR for all active video games was significantly greater than boys, tending towards significance for sedentary video gaming. Data from a video gaming experience questionnaire indicated that girls had a lower volume of video game play per week compared to the boys. The observed HR differences may be attributable to the level of video gaming experience of participants, with the more experienced gamers (boys) having lower HRs due to a depressed emotional response, such as reduced anxiety (Livingstone et al. 2000; Sell et al., 2008). Conversely, the cardiorespiratory fitness of boys may have been greater than girls, and this would mediate a higher stroke volume, and hence a lower HR in boys for all the activities (Saris et al., 1980; Livingstone et al., 2000).

Based on a 200 beat·min^{-1} maximum HR (HR_{max}), which has been reported in youth during treadmill running (Bar-Or, 1983; Armstrong et al., 1991) and recommended as a target HR in maximal tests for youth (Armstrong and Welsman, 1994), group HR data from boxing indicated that the intensity reached corresponded to 67% of HR_{max}. This is comparable to that observed in youth during dance simulation (Tan et al., 2002; Unnithan et al., 2006; Maddison et al., 2007) and active video gaming on the Sony EyeToy (Maddison et al., 2007). These PA intensities have been concluded as sufficient for developing or maintaining cardiorespiratory fitness in youth (Tan et al., 2002; Unnithan et al., 2006), as they exceeded the ACSM recommendation of 60% of HR_{max} (Pollock et al., 1998). However, this recommendation is for adults, with a recent review indicating that to improve cardiorespiratory fitness in young people, training should be of intensity higher than 80% HR_{max} (Baquet et al., 2003). This greater intensity for youth may be due to a relatively high initial peak $\dot{V}O_2$ compared to adults, perhaps due to greater levels of PA than adults, which would contribute to a decreased sensitivity to training (Baquet et al., 2003; Rowland, 1992). Thus, these active video games are unable to stimulate sufficient PA intensities for the maintenance of cardiorespiratory fitness.

For Wii Sports boxing, the group mean for HR was comparable to that reported for dance simulation. However, boxing elicited a lower energy cost. It is likely therefore that boxing increased HR disproportionately compared to $\dot{V}O_2$ by stimulating a heightened emotional response. Further, the lower EE for boxing seems attributable to the predominant stimulation of upper body movement and hence smaller muscle groups, compared to greater stimulation of the large muscle groups in the lower body during dance simulation. This is supported by higher activity counts from the right hip in children during dance simulation (1288 (619) CPM; Maddison et al., 2007) compared to boxing (380 (611) CPM). Nevertheless, HR and $\dot{V}O_2$ in both forms of active video gaming demonstrated a similar disassociation; with $\dot{V}O_2$ failing to increase to the same proportion as HR. Unnithan et al. (2006) hypothesised this disassociation was due to the lack of upper body movement during dance simulation. For Wii boxing the disassociation could be explained by the lack of total body movement. Therefore, it is possible that an active video game stimulating whole body movements could minimise the disassociation between HR and $\dot{V}O_2$.

An example of a whole body active video game is Homerun on the Sony EyeToy. Homerun encourages gamers to swing their arms to hit a ball and then run or jump on the spot while simultaneously waving their arms to move a character (Maddison et al., 2007). This game has been reported to have a similar energy cost to dance simulation (Maddison et al., 2007). Therefore, the HR-$\dot{V}O_2$ disassociation is probably due to the intermittent nature of active video gaming, with rest periods leading to transient decreases in these variables, as previously suggested (Unnithan et al., 2006). The development of active video games that encourage more continuous game play may alleviate the disassociation between HR and $\dot{V}O_2$, and increase a young person's EE. It is important however that continuous active video game play is fun for young people and is an enjoyable alternative to sedentary video gaming. This is because enjoyment is a valued trait when choosing to participate in an activity (Dishman et al., 2005). Furthermore, Epstein et al. (2007) reported non-overweight and overweight children to be more motivated to play a sedentary video game rather than an active version of the game due to the active alternative feeling too much like exercise or being too physically demanding. This suggests that more continuous active video game play should not be too intense; otherwise physical sensations may override enjoyment and reduce participation. Beyond the study of Epstein et al. (2007), research exploring the enjoyment derived from active video games is sparse, with further evidence required to improve our understanding of the potential acceptability of active video games.

This study was limited by the small sample size of lean adolescents aged 11 to 17 years. Thus, it is not possible to generalise the results to larger samples or other populations, who may have exhibited different physiological responses. Non-significant predictors of EE cannot be ruled out, as they may be significant in larger data sets. The results are also only applicable to Wii Sports, which encourages greater activity than other Wii games. To calculate percentage of HR_{max} data for each active video game, a HR_{max} value of 200 beats·min^{-1} was used across the sample. In view of the variability of HR_{max} between children and adolescents (Armstrong et al., 1991), the conclusions would have been strengthened if based on directly measured values acquired from a maximal test. In the context of this study however, it is believed that directly measured HR_{max} would not change to the main conclusion related to this data, which was that the investigated active video games were unable to stimulate exercise intensities required for the maintenance of cardiorespiratory fitness in youth. This study was laboratory-based and may not have replicated conditions in the home where typical video gaming occurs. However, instructions provided for home use were followed, and energetic responses are unlikely to be significantly different in a home-based study. Participants played each video game for 15 min during the experimental trial. While this duration is similar to studies assessing the energy costs of activities in youth (Harrel et al., 2005; Lanningham-Foster et al., 2006; Maddison et al., 2007), future research may seek to determine if the PA levels exhibited are replicated over longer gaming periods in the home, rather than a laboratory setting. Further, these games may only serve to sizeably increase total EE over a week if they maintain player interest for sufficient durations. The utility of the Nintendo Wii as an intervention cannot be identified from this study, though findings suggest that it may have potential in an adolescent population for increasing EE.

4.5 Conclusion and future research

The physiological cost of upper-body orientated active video games increased when movement of both upper limbs was encouraged. For the investigated non-ambulatory active video games, the best single-measure for predicting EE was an accelerometer on the hip, which is congruent with recommendations provided for site placement when assessing habitual PA (Rowlands, 2007). When multiple measurement tools were used to explain the variance in EE during active video gaming, multi-site activity monitoring at the hip and wrist provided similar predictions to the commonly used combination of HR and hip activity data. Furthermore, the improvements in explanatory power of multi-site activity monitoring provided support for the assessment of upper limb movements during non-ambulatory activities, such as active video gaming, in adolescents. Though only Wii Sports boxing increased EE to moderate intensities, results suggest that if video game players replaced sedentary video gaming with play on any of the investigated active video games and sustained this, a potentially large excess in EE can occur that could contribute to weight management.

A growing body of research supporting the energy expending benefits of active video gaming over sedentary video gaming in children and adolescents is now emerging. No evidence exists however comparing the physiological cost of active video gaming in children or other populations to aerobic forms of exercise common to daily living, such as walking and jogging. This would further contextualise the energy expending potential of active video games in individuals of varying age. Assessing physiological responses to active video gaming across a wide age range would also indicate whether the magnitude of PA and EE observed in young people is similar in adults. If similar physiological responses were observed between young people and adults, this would support the promotion of active rather than sedentary video gaming throughout the lifecourse. Investigating whether the enjoyment of active video gaming is similar to sedentary video games or aerobic exercise is an additionally pertinent question in order to gain an insight into the potential acceptability of these devices. This would inform interventions that aimed to use active video games to promote PA and reduce the time spent sedentary.

Chapter 5

The Physiological Cost and Enjoyment of Active Video Gaming, Sedentary Video Gaming and Aerobic Exercise in Adolescents, and Young and Older Adults

The physiological cost and enjoyment of active video gaming, sedentary video gaming and aerobic exercise in adolescents, and young and older adults

The main outcomes of this study have been accepted for publication in the Journal of Physical Activity and Health (Graves, L. E. F., Ridgers, N. D., Williams, K., Stratton, G., Atkinson, G., Cable, N. T. (in press). The physiological cost and enjoyment of Wii Fit in adolescents, young adults and older adults. *Journal of Physical Activity and Health*) (please see Appendix 2).

5.1 Introduction

Cross-sectional research indicates that active video games such as Wii Sports, dance simulators and those on the Sony EyeToy significantly increase PA and EE compared to sedentary video games in children and adolescents (Lanningham-Foster et al., 2006; Maddison et al., 2007; Graves et al., 2007; 2008). This is supported by two further studies. In twenty 9 to 12 year old children, Straker and Abbott (2007) found HR and EE for four forms of sedentary video gaming to be significantly lower than a moderately-intense active video game (Cascade, Sony EyeToy). In eighteen 6 to 12 year old children, Mellecker and McManus (2008) found an activity-based bowling game and a game requiring participants to jump, squat, side step and stamp on a gaming mat (XaviX bowling® and XaviX J-Mat®, SSD Company Ltd, Shiga, Japan) to elicit light and vigorous intensity PA, respectively, which were significantly greater than the PA levels reported for a sedentary video game. However, active video games investigated in the published literature have focused on a small range of activities and sports. Further, physiological responses to active video gaming have not been compared in the same sample to exercise or authentic versions of the game, which would further contextualise the energy expending potential of these devices.

Research is also generally limited to youth aged 6 to 16 years. Adults enjoy playing video games (Wood et al., 2004; 2007) similar to young people (Pratchett, 2005; Marshall et al., 2006). Therefore, if adults exhibit similar physiological responses to young people during active video gaming, this would support the promotion of active rather than sedentary video gaming throughout the lifecourse. Promoting PA through active video games may also appeal to adults who do not enjoy exercise. Thus, given the high prevalence of overweight and obesity (Ogden et al., 2006) and low levels of PA in adults (Varo et al., 2003), the use of active video games as a novel tool to encourage PA in people of all ages should be investigated.

In 2008 an interactive fitness video game (Wii Fit®, Nintendo Wii, Nintendo Co Ltd, Minami-ku Kyoto, Japan) was launched to engage people of all ages in a range of home-based exercises. Exercises on Wii Fit are categorised into four training modes; yoga poses, muscle conditioning, balance games and aerobic exercise. Whilst Wii Fit may provide alternative opportunities for PA in the home, it is important to assess the physiological cost of this new form of gaming and contextualise findings in relation to PA guidelines that are recommended for health benefits. Current guidelines for children and adults are to accumulate at least 60 and 30 $min \cdot d^{-1}$ of at least moderate intensity PA (Biddle et al., 1998; DH, 2004), respectively, with evidence of light-to-moderate intensity PA providing health benefits in older adults (DH, 2004). Increasing total PA and NEAT through activities not necessarily of moderate-to-vigorous intensity may also promote metabolic health in youth (Ekelund et al., 2007) and regulate weight gain in adults (Levine, 2007), respectively. To improve cardiorespiratory fitness in adults and young people, participation in activities of intensity greater than 60% HR_{max} (Pollock et al., 1998) and 80% HR_{max} (Baquet et al., 2003) are recommended, respectively. Thus, comparing the PA intensity of aerobic exercises on Wii Fit with these guidelines seems pertinent for contextualising their possible health benefit.

Investigating whether young people and adults enjoy active video gaming is also important as enjoyment of an activity is a key determinant influencing the allocation of one's time to that pursuit (Dishman et al., 2005; Kolt et al., 2004). If people enjoy active video gaming and this is sustained, regular participation over time may benefit PA engagement and accrual. Research suggests young people may choose to allocate time to active rather than sedentary screen-based media (Epstein et al., 2007; Mellecker et al., 2008). In a laboratory setting, eighteen overweight and seventeen non-overweight 8 to 12 year old children were found to be more motivated to play an active dance video game compared to a sedentary equivalent when given the choice, perhaps due to the interactive nature of the active game (Epstein et al., 2007). In their study, Mellecker et al. (2008) tested the feasibility and acceptability of a walking media station in children aged 6 to 13 years. The station allows normal seated screen-based activities to be performed whilst walking. In a laboratory-based protocol, eighteen children with a normal group mean for BMI (18.5 $kg \cdot m^{-2}$) successfully played a bowling computer game with a mouse whilst using the station, with no significant difference in game score to that achieved during seated play on the same game (Mellecker et al., 2008). In a home-based protocol, eleven different children, for whom descriptive characteristics were not presented, were more motivated to use the station to play Nintendo Wii or PS video games compared to playing the same games seated (Mellecker et al., 2008). Children stated they would play their video games on the station if it was theirs to keep (Mellecker et al., 2008). The authors concluded that re-engineering PA into normally seated activities provides an innovative and creative opportunity for increasing PA, whilst minimising disruption to normal routines (Mellecker et al., 2008). Similar to the study by Epstein et al. (2007) however, these observations were from short testing protocols. Results may also have been influenced by the novelty of the technology and the presence of researchers in the home setting. Nevertheless, these studies suggest that replacing sedentary video gaming with activity-based equivalents may be appealing to youngsters.

Beyond the studies of Epstein et al. (2007) and Mellecker et al. (2008), research investigating the enjoyment of other active video games across different age groups is scarce. Investigating whether the enjoyment derived from active video gaming is similar to seated video gaming or aerobic exercise will provide an insight into the behaviours that individuals may prefer to engage in. This could inform future interventions that use active video gaming protocols. The aim of this study therefore was to evaluate the physiological cost and enjoyment of adolescents, and young and older adults while playing Wii Fit, comparing this with sedentary video gaming, brisk treadmill walking and treadmill jogging. Specific objectives were to compare EE, HR and enjoyment between handheld sedentary video gaming and Wii Fit activities (yoga, muscle conditioning, balance, aerobics), and, aerobic activities on Wii Fit (Wii aerobics), brisk treadmill walking and treadmill jogging.

5.2 Method

5.2.1 Participants and setting

Fourteen adolescents (age range 11 to 17 years; four female, ten male), fifteen young adults (21 to 38 years; eight female, seven male) and thirteen older adults (45 to 70 years; three female, ten male) participated in the present study. Participants were recruited via word of mouth and had no previous experience of Wii Fit. Participants, and when applicable their parents, gave written informed assent and consent, respectively, and the study was approved by the University ethics committee. All testing took place at RISES.

5.2.2 Procedure

5.2.2.1 Anthropometry

Stature and body mass were measured using the same equipment and standard anthropometric techniques as study one. Body mass index (BMI) was calculated as mass divided by stature ($kg{\cdot}m^{-2}$).

5.2.2.2 Resting measurements and familiarisation

On separate days to experimental trials, and following at least 2 h of fasting and 5 min of supine rest, resting $\dot{V}O_2$ and RHR were measured for 15 min in a quiet darkened room using a portable MetaMax 3B indirect calorimetry system and accompanying facemask, and, ECG monitoring through the MetaMax 3B, respectively. This measurement duration is similar to previous research and provides sufficient time for steady state to be achieved (Mifflin et al., 1990; Harrel et al., 2005).

Participants were familiarised with the handheld sedentary video game Tetris (GameBoy, Nintendo Co Ltd, Minami-ku Kyoto, Japan; http://www.tetris.com/), the active video game Wii Fit (http://uk.wii.com/wii/en_GB/software/wii_fit_909.html) and aerobic exercises of brisk walking and jogging on a motorised treadmill (H P Cosmos, Traunstein, Germany). Tetris is an externally-paced falling-blocks puzzle video game, where players join different shapes to make horizontal lines via the use of the D pad and A and B buttons on the console. A game finishes when the screen is full of shapes and lines cannot be completed. Wii Fit is an exercise game that has fifty exercises within four training categories (yoga poses, muscle conditioning, balance games, aerobic exercises). Most exercises, except *Jogging* for example (please see Appendix 1), require a player to interact with the Wii Balance Board (dimensions 34.3 x 52.1 x 8.1 cm) peripheral device. The wireless Board is a video game controller that is placed on the floor in front of the media output device, and contains sensors that measure the player's centre of pressure when stood on.

For Tetris, seated participants used the handheld GameBoy console to play the game for 5 min. For Wii Fit, standing participants completed three exercises in each of the four training categories (yoga poses, muscle conditioning, balance games, aerobic exercises) in the Trial mode. The exercises completed are described in Appendix 1. The Wii Balance Board was placed on the floor 3 m from a screen, and without shoes, participants were directed to follow on screen instructions and perform each exercise in a comfortable manner. Participants were provided with assistance if required to help maintain balance. For each aerobic exercise on the treadmill, participants were asked to 'walk briskly' and 'jog' at a self-selected speed for 5 min. This study additionally involved participants reporting their level of enjoyment following an activity in the experimental trial, through a short form of the Physical Activity Enjoyment Scale (PACES) (Kendzierski and DeCarlo, 1991). Following familiarisation to these activities therefore, the same researcher (LG) familiarised participants to the items they would respond to on the scale and encouraged them to raise any questions or concerns. During familiarisation participants wore a portable MetaMax 3B system with an accompanying facemask and 5-leads for ECG monitoring attached to participants via ECG electrodes.

5.2.2.3 Experimental trial

Each participant performed one experimental trial. Participants were fitted with the portable MetaMax 3B system with an accompanying facemask and 5-leads for ECG monitoring attached via ECG electrodes. Participants performed each of the following seven activities for 10 min, in the order listed, interspersed with 5 min seated rest;

handheld sedentary video gaming (Tetris), yoga exercises (Wii Yoga), muscle conditioning exercises (Wii muscle conditioning), balance exercises (Wii balance), aerobics exercises (Wii aerobics), brisk treadmill walking, treadmill jogging. This order was perceived to represent a progressive increase in exercise intensity. Following each activity, participants completed the short form of the PACES.

For handheld sedentary video gaming on Tetris, seated participants played on the single player mode starting at the easiest level. Once a game finished the activity was restarted and this continued throughout the 10 min. For each Wii Fit activity, standing participants performed the three exercises practised during familiarisation in the order stated (please see Appendix 1). Once the three exercises were completed the participant restarted the sequence and continued this for the 10 min. Though directed to follow onscreen instructions a range of movements were observed, including actions similar to those requested and modified movements that allowed participants to perform exercises within their physical limits. Several older adults marched on the spot for *Jogging*. For brisk treadmill walking and jogging, participants exercised at the self-selected speeds determined at familiarisation.

5.2.3 Instrumentation

5.2.3.1 Gas analysis and heart rate

Expired air and HR were measured during the resting protocol and experimental trial by a portable MetaMax 3B. For system details and methods of its use for assessing $\dot{V}O_2$ please see Chapter 4. Heart rate was measured using 5-lead ECG monitoring. Data were recorded using MetaMax software (Statera Edition, Version 3). Participant movements were not restricted during activities by this monitoring approach. Leads were attached to participants via ECG electrodes. The arm electrodes were placed at the infra-clavicular fossa's on the left and right shoulders. Leg electrodes were placed at the level of the lowest ribs on the thorax. The V_1 chest electrode was placed in the fourth intercostals space at the right sternal border. Throughout resting and trial periods $\dot{V}O_2$ and HR data were averaged over 15-s epochs. Raw data for each measurement period were exported from the manufacturer software in 15-s epochs and analysed on a personal computer.

Heart rate data was lost for one participant (female young adult) during treadmill walking due to monitoring problems.

5.2.3.2 Enjoyment

Enjoyment of each activity was assessed using a short version of the original PACES (Kendzierski and DeCarlo, 1991) (please see Appendix 1). The original PACES consists of eighteen seven-point bipolar items (e.g. "I enjoy it...I hate it"). The items were generated from examination of the exercise adherence and exercise enjoyment literature, examination of dictionary and thesaurus entries, discussions between the authors about affective experiences regarding PA, interviews conducted with individuals with varying attitudes towards PA, and consultations with three experts in the field of exercise adherence (Kendzierski and DeCarlo, 1991). Following an activity, individuals rate the extent to which they agree with each item on the seven-point Likert-type scale, and the responses are summed to produce a total enjoyment score. The original PACES begins with the stem "Please rate how you feel *at the moment* about the physical activity you have been doing".

In college students, Kendzierski and DeCarlo (1991) found that the PACES demonstrated acceptable internal consistency following cycle ergometry and abdominal exercises (Cronbach's (1951) coefficient alpha 0.93). The scales also demonstrated acceptable test-retest reliability for repeated cycling and jogging activities (intra-class correlations 0.60 and 0.93, respectively), and, provided a valid measure of enjoyment of specific physical activities, as a significant relationship between participants PACES scores and activity choice was observed (Kendzierski and DeCarlo, 1991). Motl et al. (2001) supported the validity of scores from the PACES as a measure of PA enjoyment in adolescent girls, though a modified sixteen item version was used. Two items were removed as they were deemed irrelevant or redundant for assessing enjoyment in the sample, and statements began with the stem "When I am physically active..." (Motl et al., 2001). Moore et al. (2009) supported the validity of this modified sixteen item PACES in a large sample of children, and Dishman et al. (2005) found a positive association between enjoyment scores from the same scale and increased PA in a large cohort of adolescent girls participating in an intervention to increase PA.

In the present study, five items from the original eighteen item PACES were used. Items were chosen to reflect the study aims and were taken from the original PACES. Items were taken from the original PACES rather than the modified sixteen item version, as a measure of enjoyment specific to each activity rather than PA in general was desired. Following each activity participants completed the five item PACES, rating the extent to which they agreed with each item on a seven-point Likert-type scale. Raw data were manually entered in a spreadsheet on a personal computer for analysis. Reliability of the five items were high for each activity using pooled data from the three age groups (Cronbach's alphas ≥ 0.74), and data from each age subgroup (adolescents ≥ 0.74, young adults ≥ 0.78, older adults ≥ 0.84), supporting the hypothesis that the items measured the same construct.

5.2.4 Data handling and statistical analyses

Mean resting $\dot{V}O_2$ ($l \cdot min^{-1}$) and RHR ($beats \cdot min^{-1}$) were calculated by averaging the 9 min of data taken from minutes 5 to 14 of the resting phase (Harrel et al., 2005). For each activity within the experimental trial, mean $\dot{V}O_2$ and HR were calculated using all data collected during the 10 min of activity. Mean $\dot{V}O_2$ values at rest and for each activity were converted into EE ($J \cdot kg^{-1} \cdot min^{-1}$) using established constants (McArdle et al., 1991) and participant body mass. Participant-specific METs were calculated for each activity by dividing the mean $\dot{V}O_2$ of the activity by resting $\dot{V}O_2$. For each participant, for each activity within the experimental trial, PACES responses from the five items were summed to give a score ranging from 5 to 35 (with a higher score signifying greater enjoyment), and a percentage enjoyment score was calculated. In the incidence of missing data, participants were only removed from any analysis that included the dependent variable missing.

Exploratory analyses were conducted to determine whether gender influenced the interaction between activity and age category. A two between-group and one within-group mixed design ANOVA was run on $\dot{V}O_2$, EE, HR and enjoyment data. First, a three-group mixed ANOVA was performed with *age group (adolescents, young adults, older adults)* and *gender* (*male, female*) as the between-subjects factors, and, *activity (rest, handheld sedentary video gaming, Wii yoga, Wii muscle conditioning, Wii* *balance, Wii aerobics, brisk treadmill walking)* as the within-subjects factor (Field, 2000). Secondly, to run comparisons including jogging data, older adults were excluded due to low compliance, and a two-group mixed ANOVA was performed with factors of *age group* (*adolescents, young adults), gender* (*male, female*) and *activity (rest, handheld sedentary video gaming, Wii yoga, Wii muscle conditioning, Wii balance, Wii aerobics, brisk treadmill walking, treadmill jogging)* (Field, 2000). Mixed design ANOVA for enjoyment did not include data at rest. The three- and two-group mixed ANOVA indicated there was no significant three-way activity x age category x gender interaction for $\dot{V}O_2$, EE, HR or enjoyment ($p > 0.05$; data not shown). The combined influence of age and activity performed therefore appeared the same for male and female participants, and gender was removed from the model and data pooled within each age category for descriptive and main analyses.

Differences between groups for descriptives and self-selected treadmill speeds were analysed using one-way ANOVA, as multiple comparison procedures perform relatively well under small deviations from normality (Field, 2000). Due to unequal sample sizes and unequal population variances for age and BMI, Gabriel's and Games-Howell post hoc procedures were used to determine where any significant differences lay between groups (Field, 2000). A mixed-design ANOVA was run on the variables $\dot{V}O_2$, EE, HR and enjoyment. First, a three-group mixed ANOVA was performed with *age group (adolescents, young adults, older adults)* as the between-subjects factor and *activity (rest, handheld sedentary video gaming, Wii yoga, Wii muscle conditioning, Wii balance, Wii aerobics, brisk treadmill walking)* as the within-subjects factor (Field, 2000). Secondly, to run comparisons including jogging data, older adults were again excluded, and a two-group mixed ANOVA was performed with factors of *age group* (*adolescents, young adults)* and *activity (rest, handheld sedentary video gaming, Wii yoga, Wii muscle conditioning, Wii balance, Wii aerobics, brisk treadmill walking, treadmill jogging)* (Field, 2000). If Mauchly's test indicated lack of sphericity and the sphericity estimate was less than 0.75, the Greenhouse-Geisser epsilon was used to correct the analysis, but when the sphericity estimate was greater than 0.75 the Huynh-Feldt epsilon correction was used (Field, 2000). In the presence of a significant main effect for activity or age group, post hoc pairwise comparisons with a Bonferroni correction for type I error control were investigated (Field, 2000). Vertical multiple comparisons amongst pairwise group means were performed with a Bonferroni correction for type I error control when the activity x age group interaction was significant (Atkinson, 2002). Vertical comparisons for the two- and three-group mixed ANOVA were conducted using independent t-tests and one-way between subjects ANOVA, respectively. Gabriel's and Games-Howell post hoc procedures were used to determine where any significant differences lay between groups for the one-way ANOVA. SPSS v14 (SPSS Inc, Chicago, USA) was used for statistical analysis with statistical significance set at $p \leq 0.05$. Results are expressed as means and standard deviations (SD).

5.3 Results

All participants completed all activities, except ten older adults (seven male, three female) who did not jog on the treadmill due to physical limitations.

5.3.1 Descriptive analyses

Table 5.1 presents descriptive characteristics and self-selected treadmill speeds of the sample. Body mass and BMI for older adults were greater than adolescents and young adults ($p < 0.01$). The treadmill speed self-selected by young adults was greater than adolescents and older adults for brisk walking and jogging ($p < 0.05$).

Table 5.1 Mean (SD) descriptive characteristics and self-selected treadmill speeds by group.

	Adolescents (n=14)	Young Adults (n=15)	Older Adults (n=13)
Age (years)	15.8 (1.3)	28.2 (4.6) *	57.6 (6.7)
Stature (m)	1.70 (0.12)	1.71 (0.10)	1.69 (0.07)
Body mass (kg)	66.2 (11.3)	65.9 (8.7)	81.5 (13.5) **
BMI ($kg \cdot m^{-2}$)	22.8 (3.3)	22.6 (1.3)	28.4 (4.4) **
Brisk treadmill walking speed ($km \cdot h^{-1}$)	5.3 (0.9)	6.1 (0.6) *	4.8 (1.0)
Treadmill jogging speed ($km \cdot h^{-1}$)	8.4 (1.1)	9.7 (0.8) *	7.7 (0.6) ‡

* $p < 0.05$ (different from adolescents and older adults, one-way ANOVA).
** $p < 0.01$ (different from adolescents and young adults, one-way ANOVA).
‡ n = 3, descriptor provided for reference.
BMI = body mass index.

5.3.2 Main analyses

5.3.2.1 Oxygen consumption, energy expenditure and heart rate

Tables 5.2, 5.3 and 5.4 show $\dot{V}O_2$, EE and HR values, respectively, at rest and for each activity by group. The three-group mixed ANOVA resulted in a significant main effect for activity for $\dot{V}O_2$, EE and HR (F = 243.55, 324.26 and 129.78, respectively, p < 0.001), as did the two-group mixed ANOVA ($\dot{V}O_2$: $F = 545.73$; EE: $F = 774.45$; HR: $F = 345.12$, $p < 0.001$). Oxygen consumption, EE and HR for all Wii Fit activities was greater than handheld gaming ($p < 0.001$) and lower than treadmill walking and jogging ($p < 0.01$). An age group main effect for EE was found on the three-group mixed ANOVA ($F = 9.47$, $p < 0.001$), with older adults having significantly lower EE compared to adolescents and young adults ($p < 0.01$). There were no main effects for age group for the two-group analysis ($p > 0.05$). The three-group mixed ANOVA resulted in a significant activity x age group interaction for EE ($F = 5.08$, $p < 0.001$). One-way ANOVA indicated significant differences between groups for handheld gaming, Wii muscle conditioning, Wii aerobics, and treadmill walking ($p_{corrected} < 0.05$), with post hoc tests indicating older adults had lower EE than adolescents and young adults ($p < 0.05$). The two-group analysis resulted in a significant activity x age group interaction for $\dot{V}O_2$ ($F = 3.27$, $p = 0.041$) and EE ($F = 4.22$, $p = 0.01$), though independent t-tests indicated no differences in these variables between groups for any activity ($p_{corrected} > 0.05$).

Table 5.2 Mean (SD) oxygen consumption ($\dot{V}O_2$) for each activity by group.

	$\dot{V}O_2$ (l·min^{-1})		
Activity	**Adolescents**	**Young adults**	**Older adults**
Rest	0.35 (0.07) *	0.31 (0.05) *	0.32 (0.07) *
Handheld gaming	0.36 (0.09) *	0.34 (0.06) *	0.32 (0.07) *
Wii yoga	0.60 (0.10)	0.57 (0.14)	0.57 (0.16)
Wii muscle conditioning	0.74 (0.12)	0.73 (0.17)	0.68 (0.22)
Wii balance	0.59 (0.11)	0.58 (0.13)	0.57 (0.17)
Wii aerobics	1.09 (0.17)	1.09 (0.22)	0.96 (0.29)
Brisk treadmill walking	1.20 (0.26) *	1.35 (0.26) *	1.17 (0.47) *
Treadmill jogging	2.21 (0.43) *	2.44 (0.35) *	

* $p < 0.01$ (different from Wii Fit activities, three- and two-group mixed ANOVA).

Table 5.3 Mean (SD) energy expenditure (EE) for each activity by group.

	EE (J·kg^{-1}·min^{-1})		
Activity	**Adolescents**	**Young adults**	**Older adults**
Rest	111.7 (22.7) *	96.9 (12.8) *	78.4 (14.2) *
Handheld gaming	113.5 (26.3) *	109.0 (13.7) *	84.1 (20.0) * †
Wii yoga	190.8 (34.6)	178.8 (33.4)	148.7 (40.9)
Wii muscle conditioning	236.8 (36.4)	230.2 (39.2)	178.7 (61.1) †
Wii balance	188.2 (31.0)	182.8 (39.0)	150.8 (50.1)
Wii aerobics	348.1 (44.7)	345.3 (59.6)	252.2 (83.6) †
Brisk treadmill walking	384.9 (81.1) *	429.7 (57.7) *	302.7 (103.7) * †
Treadmill jogging	697.7 (89.9) *	764.7 (89.4) *	

* $p < 0.01$ (different from Wii Fit activities, three- and two-group mixed ANOVA).
† $p < 0.05$ (different from adolescents and young adults, three-group mixed ANOVA).

Table 5.4 Mean (SD) heart rate (HR) for each activity by group.

	HR (beats·min^{-1})		
Activity	**Adolescents**	**Young adults**	**Older adults**
Rest	67.9 (12.7) *	58.3 (8.2) *	68.0 (12.3) *
Handheld gaming	70.9 (13.1) *	65.6 (8.7) *	74.0 (9.7) *
Wii yoga	86.6 (16.2)	77.6 (10.5)	83.8 (9.5)
Wii muscle conditioning	90.2 (15.3)	82.4 (11.9)	86.8 (10.2)
Wii balance	85.0 (15.6)	76.7 (10.9)	84.5 (9.9)
Wii aerobics	101.9 (18.4)	94.5 (10.1)	94.7 (11.2)
Brisk treadmill walking	111.8 (17.5) *	108.3 (11.4) *	102.5 (15.0) *
Treadmill jogging	154.9 (19.4) *	153.7 (12.0) *	

* $p < 0.01$ (different from Wii Fit activities, three- and two-group mixed ANOVA).

Table 5.5 shows the MET intensity of each activity by group. For all groups, all activities were of light intensity (< 3 METs) except Wii aerobics and brisk treadmill walking (moderate, 3 to 6 METs), and treadmill jogging (vigorous, > 6 METs). For adolescents, based on a HR_{max} of 200 beats·min^{-1} (Bar-Or, 1983; Armstrong et al., 1991; Armstrong and Welsman, 1994), the intensity of Wii aerobics corresponded to 51% HR_{max}, treadmill walking 56%, and treadmill jogging 77%. For young and older adults, HR_{max} was estimated using the equation: $HR_{max} = 205.8 - (0.685*age)$ (Inbar et al., 1994), which has been reported as the most accurate general equation for estimating HR_{max} in adults (Robergs and Landwehr, 2002). Respective intensities elicited for young and older adults were 51% and 57% HR_{max} for Wii aerobics, 58% and 62% for treadmill walking, and 82% for treadmill jogging in young adults.

Table 5.5 Mean (SD) metabolic equivalents (METs) for each activity by group.

	METS		
Activity	**Adolescents**	**Young adults**	**Older adults**
Handheld gaming	1.0 (0.1)	1.1 (0.1)	1.1 (0.3)
Wii yoga	1.7 (0.3)	1.9 (0.4)	1.9 (0.4)
Wii muscle conditioning	2.2 (0.4)	2.4 (0.4)	2.3 (0.6)
Wii balance	1.7 (0.4)	1.9 (0.5)	1.9 (0.5)
Wii aerobics	3.2 (0.7)	3.6 (0.8)	3.2 (0.8)
Brisk treadmill walking	3.5 (0.5)	4.5 (1.0)	4.0 (1.5)
Treadmill jogging	6.5 (1.5)	8.0 (1.2)	

5.3.2.2 Enjoyment

Table 5.6 shows the PACES enjoyment score, as a percentage, for each activity by group. The three- and two-group mixed ANOVA resulted in a significant main effect for activity for enjoyment (respective $F = 13.46$ and 16.20, $p < 0.001$). The three-group analysis indicated enjoyment for all Wii Fit activities was greater than handheld gaming ($p < 0.01$), except Wii yoga ($p > 0.05$), and greater for Wii balance and Wii aerobics compared to treadmill walking ($p \leq 0.05$). The two-group analysis indicated enjoyment for all Wii Fit activities was greater than handheld gaming ($p < 0.05$), greater than treadmill walking for Wii muscle conditioning, Wii balance and Wii aerobics ($p < 0.05$), and, greater than treadmill jogging for Wii balance and Wii aerobics ($p < 0.05$). There were no main effects for age group for either ANOVA ($p > 0.05$). The three-group analysis resulted in a significant activity x age group interaction ($F = 2.73$, $p = 0.011$). One-way ANOVA indicated differences between groups for treadmill walking ($p_{corrected} = 0.004$), with post hoc tests indicating older adults had higher enjoyment than adolescents and young adults ($p < 0.05$). Though the two-group analysis resulted in a significant activity x age group interaction for enjoyment ($F = 3.71$, $p = 0.005$), independent t-tests indicated no differences between adolescents and young adults ($p_{corrected} > 0.05$).

Table 5.6 Mean (SD) Physical Activity Enjoyment Scale (PACES) percentage score for each activity by group.

Activity	Enjoyment (%)		
	Adolescents	**Young adults**	**Older adults**
Handheld gaming	60.8 (18.8) * ‡	62.1 (11.0) * ‡	72.3 (22.1) *
Wii yoga	78.6 (15.0)	67.0 (12.4)	70.3 (25.0)
Wii muscle conditioning	77.8 (16.9)	74.7 (13.0)	80.0 (18.4)
Wii balance	84.3 (15.1)	80.8 (12.1)	85.5 (14.2)
Wii aerobics	90.4 (9.8)	85.3 (13.6)	80.4 (15.4)
Brisk treadmill walking	65.5 (17.1) † ¥	69.3 (14.9) † ¥	86.2 (10.4) † ^
Treadmill jogging	59.8 (24.8) °	77.3 (13.3) °	

* $p < 0.01$ (different from Wii muscle, Wii balance, Wii aerobics, three-group mixed ANOVA).
† $p \leq 0.05$ (different from Wii balance, Wii aerobics, three-group mixed ANOVA).
‡ $p < 0.05$ (different from Wii Fit activities, two-group mixed ANOVA).
¥ $p < 0.05$ (different from Wii muscle, Wii balance, Wii aerobics, two-group mixed ANOVA).
° $p < 0.05$ (different from Wii balance, Wii aerobics, two-group mixed ANOVA).
^ $p < 0.05$ (different from adolescents and young adults, thee-group mixed ANOVA).

5.4 Discussion

Active video games significantly increase EE compared to sedentary video games in young people (Lanningham-Foster et al., 2006; Maddison et al., 2007; Graves et al., 2007; 2008; Straker and Abbott, 2007; Mellecker and McManus, 2008). A paucity of research exists, however, examining the physiological responses to active video gaming in older populations, or comparing these responses with those for exercise or authentic versions in the same sample. This would further contextualise the potential health benefit of active video games. Research investigating whether individuals enjoy playing active video games is also scarce. Furthermore, enjoyment of active video games has not been compared to sedentary video games and aerobic exercise. This would provide an insight into the behaviours that individuals may prefer to engage in and inform the suitability of interventions using active video game protocols. The aim of this study was to evaluate the physiological cost and enjoyment of adolescents, and young and older adults while playing Wii Fit, comparing this with sedentary video gaming, brisk treadmill walking and treadmill jogging.

For all participants, EE and HR during yoga, muscle conditioning, balance and aerobic Wii Fit activities were significantly greater than handheld sedentary video gaming. In contrast, original results from three populations suggest that EE and HR during the most intense game activity, Wii aerobics, were significantly lower than brisk treadmill walking and treadmill jogging. The lower energy cost of Wii Fit is likely due to fewer body movements and hence muscle contractions being performed compared to during treadmill exercise, as a result of the intermittent (Unnithan et al., 2006) and at times non-ambulatory nature of gaming. This suggests that though active video games increase EE compared to sedentary video games in individuals of all ages, they are not as costly in terms of EE compared to authentic forms of exercise.

In all age groups Wii aerobics elicited moderate intensity PA. For young and older adults this is comparable to activities of trampolining and walking leisurely (Ainsworth et al., 2000). For adolescents, this PA intensity for Wii aerobics is less than the vigorously intense active video game XaviX J-Mat (Mellecker and McManus, 2008) but comparable to other moderately intense games including Wii Sports boxing (Graves et al., 2008), Homerun, Knockout and Cascade on the Sony EyeToy (Maddison et al., 2007; Straker and Abbott, 2007), and Dance UK on the PS2 (Maddison et al., 2007). In contrast, Wii yoga, muscle conditioning and balance activities were of light intensity and comparable to the games Wii Sports bowling and tennis (Graves et al., 2008), Nicktoons Movin', Groove and AntiGrav on the Sony EyeToy (Lanningham-Foster et al., 2006; Maddison et al., 2007) and XaviX bowling (Mellecker and McManus, 2008). These findings indicate that vigorous intensity PA is rarely elicited through active video gaming, and from the present study only time spent participating in the described Wii aerobics activity would contribute to adolescent and adult recommendations for health benefiting PA (Biddle et al., 1998; DH, 2004). However, for older adults, PA recommendations suggest that participation in the light-to-moderately intense Wii Fit activities may help reduce the risk for all cause-mortality, cardiovascular disease and type-2 diabetes (DH, 2004). Moreover, a sustained increase in low intensity and total PA through the conversion of screen time from sedentary to active may benefit metabolic health and regulate weight gain (Ekelund et al., 2007; Levine, 2007). Future research in this field should aim to distinguish whether active video gaming can benefit health by increasing low intensity and total PA. Interventions using Wii Fit may also assess changes in components of fitness targeted by the game, such as muscular strength and endurance, cardiorespiratory fitness, balance, coordination and flexibility.

To maintain or develop cardiorespiratory fitness, young people and adults are recommended to exercise at respective intensities of 80% HR_{max} (Baquet et al., 2003) and 60% HR_{max} (Pollock et al., 1998). In the present study, only self-paced treadmill walking in older adults and treadmill jogging in young adults met these targets. The inability of the investigated Wii Fit aerobics activity to elicit sufficient intensities for cardiorespiratory fitness maintenance in youth is similar to observations for dance simulators (Tan et al., 2002; Unnithan et al., 2006; Maddison et al., 2007), Wii Sports (Graves et al., 2008) and EyeToy games (Maddison et al., 2007). It is important to note however that the exercises available in the Trial mode are the easiest available and not representative of all exercises on Wii Fit. Exercises in the main section of the game may be more difficult and elicit higher EE and/or HR; however these are unlocked through sustained participation, hence why the Trial mode was used.

Differences in the physiological cost of activities between groups were observed, with older adults' EE lower than adolescents and young adults during handheld sedentary video gaming, Wii muscle conditioning, Wii aerobics, and brisk treadmill walking. For the active video games, this EE difference is likely attributable to physical limitations in older adults inhibiting their ability to perform the full ranges of motion required. The consequential modified actions that allowed older adults to perform the exercises with less physical discomfort would result in reduced muscle contraction and hence EE. For brisk treadmill walking, EE differences are likely explained by older adults self-selecting the lowest speed of all the age groups.

Results from the PACES indicated a generally high level of enjoyment (> 70%) for all Wii Fit activities across groups. The enjoyment derived from handheld sedentary video gaming was significantly less than Wii Fit activities, except for yoga in the three-group analysis. This was due to older adults' comparable enjoyment of yoga and sedentary gaming. Enjoyment is an important determinant influencing the time an individual allocates to an activity (Dishman et al., 2005; Kolt et al., 2004). Thus, if participants were given the choice to play either sedentary or active video games on these devices on a separate occasion, they may choose an active alternative. This is supported by research in thirty-four college students, which found a significant positive relationship between participants' predicted choice of activity, based on their PACES scores for two activities, and their actual choice of activity in a subsequent session (Kendzierski and

DeCarlo, 1991). This is also congruent with observations that when given the choice, children are more motivated to play video games in an active rather than sedentary manner, lending support to the notion that active video games may be enjoyable mode of entertainment for young people (Epstein et al., 2007; Mellecker et al., 2008). It is important to acknowledge that caution must be taken if extrapolating these findings to other sedentary video games, as their relationship with enjoyment is likely to differ due to factors such as game type, graphics and game quality, and the rate of absorption into the game (Wood et al., 2004). Future research is warranted to investigate the impact of video game characteristics on short and long-term enjoyment of gaming.

The enjoyment derived from the balance and aerobic Wii Fit activities was greater than brisk treadmill walking and treadmill jogging in adolescents and young adults. With regard to the aerobic Wii Fit activities, this suggests that individuals may be more motivated to engage in this type of aerobic exercise compared to that on a treadmill, perhaps due to the physical and mental demands of the game (Epstein et al., 2007). This is supported by suggestions that repetitive activities such as walking can to lead to boredom (Geiwitz, 1966), which is not viewed as an enjoyable state (Smith, 1981). Thus, if typically sedentary individuals, who may not adhere to regular aerobic exercise as they do not enjoy it, enjoy active video gaming similarly to adolescents and adults in the present study, they may be more likely to engage in this activity over sustained period. While active video games are clearly not as costly in terms of EE as brisk walking and jogging, they could be useful for introducing low levels of PA into a typically sedentary individual's daily routine, and may serve as a catalyst for participation in other forms of PA.

The greater enjoyment of Wii aerobics compared to treadmill exercise in adolescents suggests that this population may be most receptive to advancing innovative technologies aiming to reduce sedentariness and stimulate PA through video gaming. This is supported by young people's familiarity and level of engagement with this technology (Marshall et al., 2006). Interestingly, of the four Wii Fit activities performed, older adults enjoyed Wii balance the most. Compared primarily to Wii yoga and muscle conditioning, this may be due to balance exercises comprising a motivational game element. Furthermore, some balance exercises were self-paced, allowing participants to dictate how and when they moved rather than conforming to onscreen character actions.

For older adults, this characteristic of an active video game seems important due to their likely movement restrictions compared to younger people. Thus, these exercises may be enjoyable methods that could potentially help improve balance in older adults and minimise age related impairments in balance, which has been shown to increase the risk of falling and fall injuries (Tinetti et al., 1988; Sattin, 1992).

This study was limited by the small sample size for each age group, which is comparable to previous research (Unnithan et al., 2006; Straker and Abbot, 2007; Graves et al., 2007; 2008; Mellecker and McManus, 2008). This was due to multiple population involvement, which provided original data on the use of active video games in groups other than youth. Participation was voluntary, hence enjoyment responses may be biased compared to individuals not volunteering, with caution warranted when generalising findings beyond this sample. Future research with larger samples and other populations are needed to replicate these findings. The study was limited by comparing active video gaming with only treadmill walking and jogging. These comparison activities were selected due to their feasibility in the research process and because they represent typical daily activities. Nevertheless, enjoyment of treadmill locomotion may differ to overground equivalents, so caution is warranted when interpreting these findings. Future research may compare the physiological cost and enjoyment of Wii Fit exercises with real-life equivalents, such as yoga and muscle conditioning exercises, or, active gaming with different play type activities.

The study was limited by the use of a handheld game rather than a console game for sedentary video gaming, which may have altered the relationship between gaming and EE or enjoyment. However, previous research found little or no difference in EE or HR between sedentary gaming on a handheld game or a gamepad, keyboard or steering wheel with pedals connected to a PS console, suggesting comparable physical effort is required across sedentary video game input devices (Straker and Abbott, 2007). Regarding enjoyment, caution must be taken if extrapolating findings to other sedentary video games, with future research exploring such differences and possible effects on sustained gaming warranted. Participants performed each activity for only 10 min during the experimental trial, similar to previous studies (Harrell et al., 2005). Longitudinal studies are needed to determine any associated changes in EE or HR with experience, and if enjoyment of Wii Fit is maintained over time or whether one habituates to the once novel games and then stops using them. The order of activities during the trial was not randomised. This allowed for the most efficient experimental design, which was necessary due to limited participant availability. An additional limitation was the potential effect of a previous activity on physiological responses in a subsequent activity. However, the 5-min seated rest period, common in this type of study (Graves et al., 2007; Maddison et al., 2007), would likely eliminate any significant effect of the previous activity. The intermittent nature of Wii Fit, inclusive of transient rest periods, would further reduce any potential effects.

To calculate percentage of HR_{max} data in adolescents and adults, a HR_{max} value of 200 beats·min^{-1} and a prediction equation were used, respectively. In view of the variability in HR_{max} between individuals (Armstrong et al., 1991; Robergs and Landwehr, 2002), use of directly measured values from a maximal test would have strengthened associated conclusions. In the context of this study though, it is thought that directly measured HR_{max} would not change the main related conclusion that the active video games were unable to stimulate exercise intensities for the maintenance of aerobic fitness. The missing treadmill jogging data for older adults resulted in the running of both three- and two-group mixed ANOVA models. However, because of this missing cell such analyses was necessary to test the between and within subjects effects across conditions. A final limitation was the use of the PACES to determine enjoyment from sedentary video gaming, as this instrument is PA specific. However, PACES was used to maintain consistency in assessment of this variable across activities and is more comprehensive than using a single item to measure enjoyment.

5.5 Conclusion and future research

The physiological cost of active video gaming on Wii Fit was significantly greater than handheld sedentary video gaming but lower than treadmill exercise for adolescents, young adults, and older adults. This suggests Wii Fit games are not as costly in terms of EE as authentic modes of PA or exercise. Physical activity intensities elicited by Wii aerobics were of sufficient intensity to contribute to daily PA recommendations for all age groups, and all Wii Fit activities encouraged light to moderate intensity PA. The enjoyment derived from Wii Fit activities was significantly greater than handheld sedentary video gaming in adolescents and young adults. Active video games may be an enjoyable mode of screen-based entertainment across all ages. Enhanced enjoyment of balance and aerobic Wii Fit activities compared to aerobic exercise may encourage sedentary individuals to sustain participation in active video gaming. Moreover, greater enjoyment of Wii aerobics compared to treadmill exercise in adolescents suggest this population may be most receptive to advancing innovative technologies aiming to reduce sedentariness and increase PA during video gaming.

A small body of cross-sectional research now provides some support, albeit from short testing periods, that young people enjoy active video gaming and may prefer to engage in this activity compared to sedentary video gaming if given the choice. Supported by the substantial body of laboratory-based research highlighting the increased energy cost of active video gaming compared to sedentary video gaming, there is now a need to investigate whether young people will choose to allocate time to active video gaming. Young people typically play video games in the home. Thus, the home seems an appropriate setting in which to investigate this. If conversion of video gaming from sedentary to active can be sustained, and does not result in a compensatory reduction in PA at other times of the day, an increase in habitual PA is inevitable. Previous interventions investigating this, by providing young people with a single active video game, are limited by failing to assess intervention effects relative to a comparison group, and failing to objectively assess changes in habitual PA. Controlled trials avoiding these limitations are warranted to determine whether young people replace sedentary video gaming with active video gaming when given the opportunity, to determine whether this is sustained, and, in doing so, whether health benefits are accrued through a reduction in sedentary time and an increase in habitual PA. This research should also assess whether compensatory changes in the time spent in other sedentary behaviours occurs as a result of the intervention, in order to better account for any changes in habitual PA.

5.6 Acknowledgements

This work was funded by Red Consultancy Group, marketing arm of Nintendo UK.

Chapter 6

Short-term Effects of an Active Video Gaming Peripheral Device on Children's Habitual Physical Activity, Behaviour Preferences and Body Composition

Short-term effects of an active video gaming peripheral device on children's habitual physical activity, behaviour preferences and body composition

The main outcomes of this study have been accepted for publication in Pediatric Exercise Science (Graves, L. E. F., Ridgers, N. D., Atkinson, G., Stratton, G. (in press). The effect of active video gaming on children's physical activity, behaviour preferences and body composition. *Pediatric Exercise Science*) (please see Appendix 2).

6.1 Introduction

Societal changes over recent decades have encouraged less physically active lifestyles that consist of large amounts of time intentionally spent in sedentary behaviours (Biddle et al., 2004; Levine, 2007). Sedentary time in youth is negatively associated with metabolic health (Ekelund et al., 2007), and young people spending more than 2 $h \cdot d^{-1}$ in sedentary screen-based behaviours are at greater risk for overweight (Laurson et al., 2008). To increase youth PA, increasing opportunities for PA is recommended (NICE, 2006). Active video games encourage PA and discourage sedentary behaviour (Maddison et al., 2007; Graves et al., 2007). Young people play sedentary video games for approximately 30 to 45 $min \cdot d^{-1}$ (Marshall et al., 2006), and similar to other areas (Gorely et al., 2004; Jago et al., 2008) this prevalence is highest in Liverpool children from lower SES groups (Fairclough et al., 2009). Financial constraints and parental concerns about outdoor safety may contribute to fewer opportunities for sport, play and PA outside of the home (Fairclough et al., 2009). Indoor active play through active video games may be an innovative method for promoting regular PA and reducing sedentary time in children from deprived areas.

Research investigating how often and for how long active video games are played in the home, and whether this positively affects habitual PA and sedentary time is limited. In 9 to 12 year old children, Chin A Paw et al. (2007) found provision of a dance simulation game insufficiently motivating to maintain regular use in the home over 12 weeks. Madsen et al. (2007) reported similar findings in 9 to 18 year olds, with self-reported use of a dance game decreasing over 6 months. Participant feedback suggested dance games were insufficiently immersive, fun, or graded in terms of game play difficulty to maintain motivation for long-term use (Chin A Paw et al., 2007; Madsen et al., 2007).

In ten children aged 10 to 14 years, who were provided with an EyeToy and dance mat for home use, Ni Mhurchu et al. (2008) found a significant increase in total PA (CPM) compared to ten controls after 6 weeks. However, it is uncertain whether this increase in PA was due to children using the active video games, as self-reported time spent playing inactive and active video games was only reported at 12 weeks. At 12 weeks, no significant increase in total PA or MVPA, as assessed by accelerometry or self-report (Physical Activity Questionnaire for Children (PAQ-C)) was observed compared to controls (Ni Mhurchu et al., 2008). This was despite intervention children spending more time playing active video games, less time playing video games overall and significantly less time playing sedentary video games compared to controls (Ni Mhurchu et al., 2008). Maloney et al. (2008) also found no significant change compared to controls in objectively measured sedentary time or PA at 10 weeks in forty 7 to 8 year olds provided with a dance game for home use, despite lower self-reported sedentary screen time and a mean use of the game for 60 $\min \cdot wk^{-1}$. The non-significant change in sedentary time may suggest that youth replaced sedentary screen time with other sedentary behaviours away from the screen. However, participation in sedentary behaviours other than those screen-based was not assessed, highlighting a need to assess a range of sedentary behaviours in order to more definitively assess the mechanisms that account for changes, or a lack of change, in PA and sedentary time (Robinson, 1999). While these studies may have been insufficiently powered to detect changes in PA, their findings suggest that active video games may not promote increased habitual PA and reduced sedentary time in the long-term.

Participants in previous interventions, however, were typically provided with a single active video game for use on a specific console. Like any sedentary video game, over familiarisation with one active video game is likely to contribute to decreased motivation for sustained use (Mellecker et al., 2008). An alternative approach may be to re-engineer PA into video games young people own and play. A peripheral device enabling this is jOG® (New Concept Gaming Co Ltd, Liverpool, UK). jOG encourages step-powered video gaming and is compatible with video games on PS2 and PS3 (Sony Co, Tokyo, Japan), and Nintendo Wii® (Nintendo Co Ltd, Minami-ku Kyoto, Japan) consoles. Gaming with the device on the PS2 in children and adults, and the Wii in adults, stimulates light and moderate intensity PA, respectively (Graves et al., unpublished data). Use of jOG in the home and its potential impact on habitual PA and sedentary time is unknown however. Therefore, this RCT evaluated the short-term effects of jOG on the habitual PA (CPM) of 8-10 year old children from lower SES groups. A secondary aim was to assess intervention effects on subcomponents of habitual PA, including sedentary time, and, behaviour preferences and body fat.

6.2 Method

6.2.1 Participants and settings

Pupils in years 4 and 5 (8 to 10 years) from three primary schools in North West England were invited to participate in the RCT. Ethical approval was obtained from the University ethics committee. Parents/guardians and children gave written informed consent and assent respectively to participate. Parents/guardians completed medical questionnaires on behalf of their child and children completed a video gaming survey (please see Appendix 1). Children were eligible to participate if they were free from the presence of chronic disease and metabolic disorders, owned a PS2 or PS3 video game console and self-reported playing these consoles for ≥ 2 h·wk^{-1}.

Fifty-eight children met the inclusion criteria and following baseline measures were randomly assigned at the individual level to one of two intervention groups, with randomisation stratified by gender. All measures took place at RISES, except habitual PA assessment. For each pupil, SES (total deprivation rank) was calculated using the 2007 Indices of Multiple Deprivation (IMD), which was derived from home postcodes entered into the Office for National Statistics (2009) online application. The total deprivation score is calculated from seven domains of deprivation (Department of Communities and Local Government, 2008). Fifty-three children's homes were located in neighbourhoods in the highest 10% for deprivation nationally. The remaining five pupils' homes were in neighbourhoods in the top 30% for national deprivation. All schools were in neighbourhoods in the highest 10% for national deprivation.

6.2.2 Intervention design

The RCT was conducted for 12 weeks during school spring term (January to April 2009). This duration was selected to fit the local authority school calendar and represented a sufficient period for observing short-term experimental effects. The trial was not registered. Fifty-eight children met inclusion criteria and following baseline measures were randomly assigned at the individual level to the jOG intervention (n=29) or comparison (COM) group (n=29). Randomisation, stratified by gender, was accomplished by drawing folded sheets of paper, each marked with a participant's code, from a hat. Allocation alternated between groups, i.e. 1st, 3rd, 5th participant into jOG group. While web or computer-based randomisation techniques exist, this randomisation procedure remains acceptable for samples of $n \leq 60$ ($n \leq 30$ per group) (Portney and Watkins, 2000). Participants and researchers were not blinded to the experimental group.

6.2.2.1 jOG intervention (jOG)

Participants were provided with two jOG devices for home-use. One researcher (LG) familiarised participants with how to use the device during a school-based session following baseline measures. jOG packaging contained instructions for use. Two devices were provided to discourage sedentary play during multiplayer gaming and encourage social play in the home. Participants who owned a PS3 were provided with two PS2 to PS3 controller converters to allow jOG to be used with this console. The device links a pedometer (PSL Limited, Kowloon, Hong Kong) worn on the hip to a standard video game controller, and encourages gamers to step on the spot in order to use directional controls to generate onscreen character movement within video games (http://www.newconceptgaming.com/products/ps2-compatible-jog/) (Figure 6.1).

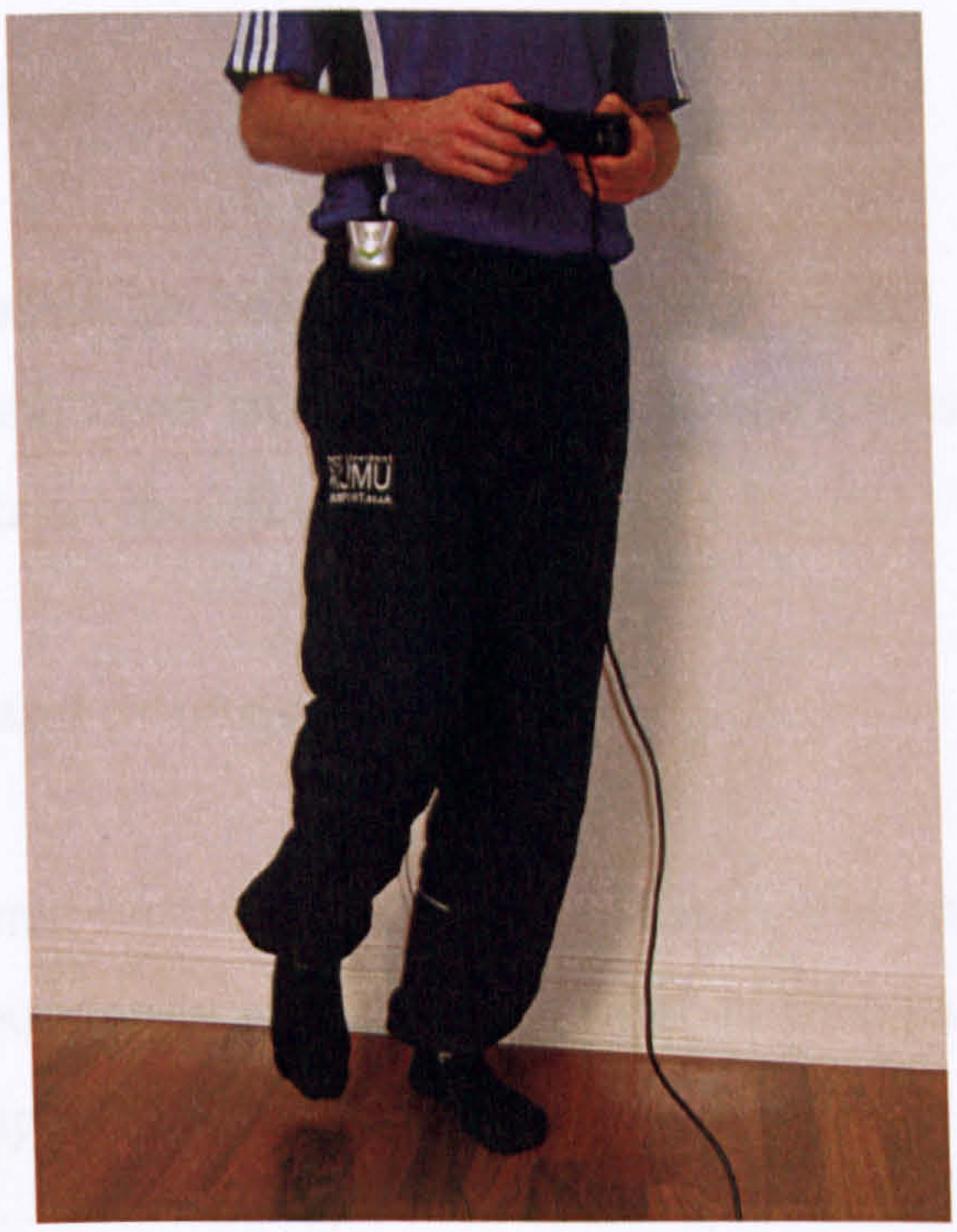

Figure 6.1 Individual engaging in step-powered video gaming with jOG. jOG, seen on the right hip, is linked to the video game controller held in both hands.

For every step recorded by the pedometer, the gamer obtains 1-s of onscreen movement. For continuous game play, sustained stepping is required. jOG includes an option to enable/disable the device, allowing games to be played without stepping whilst jOG is connected to the console. Though children were not verbally informed of this, the jOG instruction manual contained this information. Participants and their parents were encouraged to play their PS video games in a step-powered manner with jOG, rather than seated with or without jOG connected to the console. Though discouraged, participants could unplug jOG from the console and play games seated. Participants were not prescribed a frequency and duration of video game play with jOG, as has been adopted in previous studies to increase children's sense of obligation to play an active video game (Maloney et al., 2008). Research suggests children are more likely to sustain positive behaviour change if they attribute the motivation for change to themselves rather than external factors (Epstein et al., 1995). Thus, the external factor of prescription was not included in this trial. Participants were allowed to keep devices after the trial. The trial used the PS compatible jOG, as it was commercially available at the time, whilst jOG for the Wii was not.

6.2.2.2 Comparison (COM)

Participants were instructed to continue playing their video games as normal and received two jOG systems upon study completion. Participants were not instructed to refrain from playing certain types of video games.

6.2.3 Instrumentation and procedure

At baseline (0 weeks), mid-test (6 weeks) and post-intervention (12 weeks) participants attended University laboratories at RISES for a series of measures. Habitual PA was also measured at these specified time points.

6.2.3.1 Habitual physical activity assessment and data analyses

Habitual PA was measured for 7 consecutive days during waking hours every 5 s by a uniaxial accelerometer (ActiGraph GT1M) worn on the right hip using an adjustable belt. ActiGraph is valid and reliable for use in child studies (Ekelund et al., 2001). At each monitoring period participants were familiarised with ActiGraph on the first day and provided with the same accelerometer. At the end of each monitoring period data were downloaded using manufacturer software (version 3.2.2, ActiGraph LLC, Pensacola, FL, USA) and checked for compliance to the monitoring protocol using a data reduction program (Mahuffe, MRC, Cambridge, UK). Sustained bouts of 20 min of zero counts indicated that the monitor had been removed, and these missing counts were removed from the final calculation of daily registered time (i.e. wear time) (Catellier et al., 2005).

To be retained for intervention analyses participants were required to provide ≥ 9 h of registered time for ≥ 3 days at 0, 6 and 12 weeks. In a large sample of 11 year old children these minimum criteria have demonstrated reasonable reliability (r = 0.7) and power (91.7%) to detect a significant difference in PA (CPM) between two groups (Mattocks et al., 2008). Forty-two children (20 CON (5 girls, 15 boys), 22 jOG (9 girls, 13 boys)) returned valid recordings at each time point (72% compliance rate). Thirteen of these forty-two children did not provide ≥ 1 valid weekend day at each time point (31%: 10 jOG, 3 CON). The remaining twenty-nine participants (69%: 12 jOG, 17

CON) provided ≥ 1 valid weekend day and ≥ 3 weekdays of recording at each time point. Of the sixteen participants (9 CON, 7 jOG) not meeting validity criteria, one (boy, CON) was excluded due to loss of monitor, one (boy, jOG) left school, and fourteen (8 CON (4 girls, 4 boys), 6 jOG (1 girls, 5 boys)) failed to wear the monitor for a sufficient amount of time.

Habitual PA data is typically analysed using activity count thresholds generated from validated regression equations, however great variation exists in established thresholds for different activity intensities (Rowlands, 2007). Considerable individual differences in counts reported in youth of the same age during walking (Ekelund et al., 2003) are likely for any standardised activity (Rowlands, 2007). Ekelund et al. (2003) accounted for individual differences by applying individually calibrated count thresholds from reference exercises (walking at 4 $km \cdot h^{-1}$ and 6 $km \cdot h^{-1}$) to habitual PA data, and the approach provided a valid indication of free-living PA. Thus, PA data in the present study were analysed using individually calibrated count thresholds determined from a motorised treadmill (H P Cosmos, Traunstein, Germany) protocol performed during each laboratory visit.

To generate individual thresholds participants wore an ActiGraph accelerometer, set to record in 5-s epochs, on the right hip throughout the protocol. The same monitor was used for, and the same researcher led, each protocol. Following treadmill familiarisation, participants walked at 4 $km \cdot h^{-1}$ for 3 min, rested for 30 s, then jogged at 8 $km \cdot h^{-1}$ for 3 min. Previous research in our laboratory indicated that at these speeds a large sample of 9-10 year old children all walked and jogged, respectively, whereas at 6 $km \cdot h^{-1}$ some walked while others jogged (Hopkins et al., 2009). Speeds of 4 $km \cdot h^{-1}$ and 8 $km \cdot h^{-1}$ were selected as reference exercises, as they differentiated between walking and jogging in children this age. Activity counts from 4 $km \cdot h^{-1}$ treadmill walking have been used to analyse habitual PA data in previous studies in youth (Ekelund et al., 2003; Andersen et al., 2006).

For each speed, the first and last 30 s of data were excluded and the mean of the remaining 2 min of data were calculated as the individual's count threshold (Hopkins et al., 2009). At each monitoring period, individual count thresholds and a sedentary threshold of 100 CPM (Treuth et al., 2004) established the time spent per valid day sedentary, between sedentary and 3.99 km·h^{-1} ($PA_{<4}$), 4 km·h^{-1} and 7.99 km·h^{-1} ($PA_{4-7.99}$) and ≥ 8 km·h^{-1} ($PA_{\geq 8}$) for each participant. Individually calibrated thresholds were applied at each measurement point, as leg length and stature, factors that influence stride length, biomechanical efficiency and activity counts generated during locomotion (Jago et al., 2007), significantly increased for both groups from baseline to week 12 ($p < 0.05$), as did sitting stature for the jOG group at week 6 ($p < 0.05$, one-way repeated measures ANOVA).

Steps taken, CPM (total activity counts / min of registered time), total physical activity (TPA: > 100 CPM) and time spent ≥ 4 km·h^{-1} ($PA_{\geq 4}$) were also determined for each valid day. The volume of each PA component per day was calculated as: total volume from valid days / number of valid days. Data were then adjusted for registered time (volume / mean registered time of valid days) to account for significant differences observed in exploratory analysis in sedentary time and $PA_{<4}$ at baseline between participants who provided ≥ 13.0 h·d^{-1}, and, 10.0-10.9 h·d^{-1} and 11.0-11.9 h·d^{-1} of valid mean recording times. PA data were therefore presented as min·h^{-1} or steps·h^{-1} of registered time.

6.2.3.2 Behaviour preference survey

The time children spent engaged in typical behaviours was assessed using a self-report survey. The survey assessed the average daily time (h·d^{-1}) spent engaged in sedentary (i.e. seated) video gaming, active video gaming (other than step-powered gaming with jOG at 6 and 12 weeks), TV viewing, computer/internet use for pleasure, working on a computer, reading for pleasure and doing homework. Participants indicated how much time they spent in minutes in these behaviors during three periods of the day: from waking until lunch, lunch until dinner, and dinner until bedtime. Questions were asked for a typical school and typical weekend day, allowing calculation of a weighted weekly estimate, where the school day provided 5/7ths of the estimate and the weekend 2/7ths. This measurement approach has been proven reliable, and by predicting theoretically relevant variables such as school performance, demonstrates appropriate predictive validity in youth (Laurson et al., 2008; Gentile and Walsh, 2002; Gentile et al., 2004). At 6 and 12 weeks intervention children similarly reported time spent playing video games in only a step-powered manner with jOG, and this contributed to the active video gaming variable. An estimate of total video gaming (sedentary, active) and time spent in productive (working on the computer, reading, doing homework) and leisure (total video gaming, TV, computer/internet use for pleasure) behaviours was calculated. Productive behaviours have been defined to increase knowledge that helps pupils improve their education and awareness, while leisure behaviours lack these gains (Feldman et al., 2003).

6.2.3.3 Anthropometry and maturation assessment

Stature and sitting stature were measured to the nearest 0.1 cm using a Leicester Height Measure (Seca Ltd, Birmingham, UK) and body mass to the nearest 0.1 kg using a calibrated mechanical flat Seca scale (Seca Ltd, Birmingham, UK) with participants wearing light clothing and without shoes (Lohman et al., 1991). Body mass index (BMI) was calculated as mass divided by stature ($kg \cdot m^{-2}$). Maturity status was estimated by calculating years from attainment of peak height velocity (PHV) (Mirwald et al., 2002). Stature, sitting stature, leg length, body mass, chronological age and their interactions were used in gender-specific equations to predict each participant's maturation offset (years from age of PHV) (Mirwald et al., 2002).

6.2.3.4 Body fat assessment

Subtotal (whole body minus the head) and trunk body fat percentage were determined by DXA (Hologic QDR series Discovery A, Bedford, MA, USA). Dual-energy x-ray absorptiometry assessment of body composition has been validated against hydrodensitometry (Wallace et al., 2006) and is a gold standard technique for assessing fat mass in children (Goran et al., 1996). Participants were scanned in the supine position whilst wearing a lightweight t-shirt and shorts (Figure 6.2). All scans were performed and analysed by the same qualified researcher (LG). The DXA scanner was calibrated daily using the lumbar spine and step phantom. The coefficient of variation (mean baseline, mid and post measures) for the repeated measurements of subtotal body fat was 0.48% and for trunk body fat 1.17%. A copy of a DXA output and DXA calibration sheets are provided in Appendix 1.

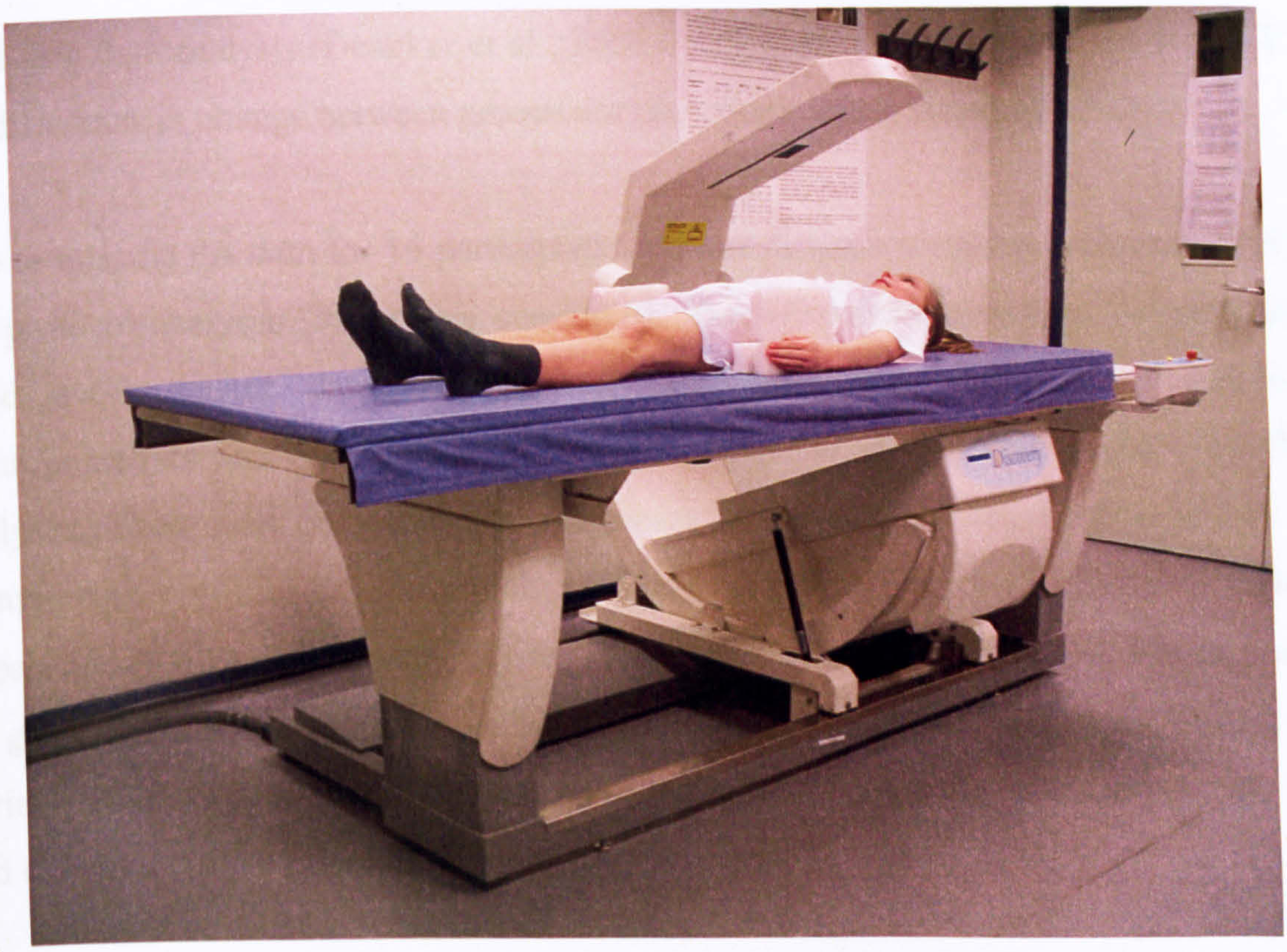

Figure 6.2 Participant in supine position during the body fat assessment scan.

6.2.4 Statistical analyses

Baseline comparability of groups was assessed using independent samples t-tests or Mann-Whitney tests, depending on the normality of data distribution by group. Analysis of covariance (ANCOVA) compared the effectiveness of the intervention at 6 and 12 weeks from baseline on the primary outcome (CPM) and all secondary outcome variables. The intervention group (jOG vs COM) was the independent variable and the variable change score (mid or post minus baseline) was the dependent variable. Covariates entered into all analysis were the baseline value for the variable to control for any imbalances at baseline (Vickers and Altman, 2001) and gender as the stratification factor. Change in maturity offset (post minus baseline) was included as a covariate in ANCOVA analyses for trunk body fat percentage, subtotal body fat percentage, $PA_{<4}$, $PA_{4\text{-}7.99}$, $PA_{>4}$, steps and CPM at 12 weeks. This indicator of maturity was included as significant correlations ($p < 0.05$; Spearman's correlations; data not shown) were observed between the appropriate changes in maturity offset and dependent variable. Maturity indicators have been used as a covariate in previous paediatric data analysis (Dencker et al., 2006). Adjusted change scores and 95% CI for the difference in change between groups are presented unless stated otherwise.

Due to missing PA data for 16 participants, known as non-compliers (Altman, 1991), a per protocol analyses (PPA) was conducted. The 16 participants who did not return valid accelerometer data had all of their data (i.e. self-report behaviours, anthropometrics and body fat) removed from baseline comparability and ANCOVA analyses. There was no significant difference between non-compliers (n = 16) and compliers (n = 42) for any anthropometric, body fat or self-reported behaviour variable at baseline ($p > 0.05$; independent t-test or Mann-Whitney test based on data normality by group; data not shown). There was similarly no significant difference for any PA variable between non-compliers who provided valid PA recordings at baseline (n = 11) and compliers (n = 42) ($p > 0.05$; data not shown).

For the primary outcome, the PPA was compared with intention-to-treat (ITT) analysis, as a sensitivity analysis (Altman, 1991). According to ITT, analysis is based on the groups as randomised, i.e. all randomised participants are included (Altman, 1991). To treat missing data, the monotone imputation technique was used. This noniterative method was selected as the data had a monotone pattern of missing values, i.e. the variables could be ordered so that if a variable has a non missing value, all preceding variables also have non missing values. The order that the variables were entered in was: independent variable (intervention group), gender, maturity offset change (for 12 week analysis only), baseline CPM, dependent variable (CPM change score). Ten imputation sets were used and the multiple imputation was based on all 58 participants. The rate of missing data was not unusually high, thus it is suggested there is minimal practical benefit of using more than five to ten imputations (Schafer, 1999). After analysing each imputed/complete data set separately by ANCOVA, the statistical significance (p) values for all the imputed/complete data sets were pooled (the mean calculated), with this providing a generally more accurate estimate than if only a single imputation occurred (Schafer, 1999). Statistical analyses were performed using SPSS v.17.0 and statistical significance was set at $p \leq 0.05$.

In addition to presenting statistical significance, effects observed from ANCOVA were evaluated for clinical importance through pre-specification of a minimum clinically important difference (MCID). This approach makes inferences based on meaningful magnitudes and has been advised by researchers (Hopkins et al., 2009). In the absence of a robust clinical anchor, MCID was determined through a distribution-based method as a Cohen's *d* (standardised difference between change scores between groups) of 0.2 between-subjects SDs (Cohen, 1988). However, the SD of pooled baseline data (n = 42) was used to negate the possibility of individual differences from the intervention influencing mid-test and post-intervention SD. Similar to previous research (McWhannell et al., 2008), the adjusted change score for a given variable was interpreted as beneficial or detrimental if it exceeded the MCID in the appropriate direction.

6.3 Results

6.3.1 Participants

Participant flow through the project is shown in Figure 6.3.

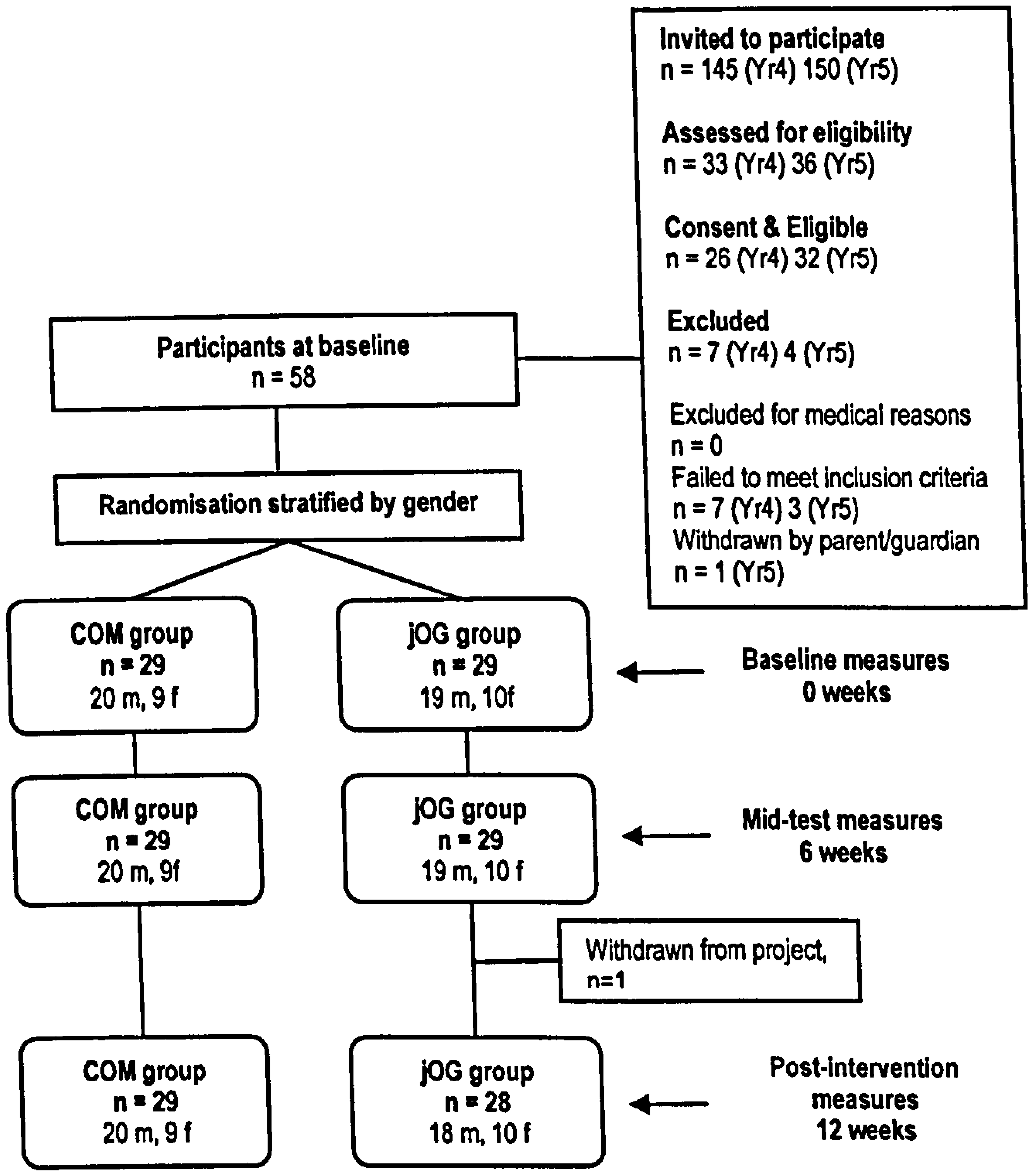

Figure 6.3 Flow of participants through the intervention

Complete data sets were available for 22 (13 boys, 9 girls; 76%) of the 29 (19 boys, 10 girls) eligible participants in the jOG group, and 20 (15 boys, 5 girls; 69%) of the 29 (20 boys, 9 girls) eligible participants in the COM group. At baseline jOG and COM participants, respectively, were comparable in age (mean (SD), 9.2 (0.5) vs 9.2 (0.5) y, $p = 0.92$), maturation offset (-3.2 (0.9) vs -3.1 (0.8) years to PHV, $p = 0.84$), number of inactive (5.8 (2.2) vs 6.6 (2.4), $p = 0.25$) and active (1.2 (0.9) vs 1.5 (0.8), $p = 0.35$) video game consoles in the home, and, typical setting of video gaming (home: 100% vs 96%, $p = 0.34$).

6.3.2 Habitual physical activity

Table 6.1 presents PA values. No baseline differences ($p > 0.05$) were observed between groups for any PA variable. Similar to the PPA, the ITT analysis indicated there was no significant difference between groups for CPM at 6 weeks (ITT mean $p = 0.173$) or 12 weeks (ITT mean $p = 0.384$). There were no other statistically significant intervention effects on PA variables. At 6 and 12 weeks, mean differences in change score between groups relative to the COM group for $PA_{4\text{-}7.99}$, $PA_{\geq 4}$, steps and CPM satisfied MCID criterion for detriment. The MCID criterions were: $PA_{4\text{-}7.99} \pm 0.6$ min·h^{-1}; $PA_{\geq 4} \pm 0.6$ min·h^{-1}; steps ± 35.2 steps·h^{-1}; CPM ± 29.6 CPM.

Table 6.1 Physical activity values for the intervention (jOG) and comparison (COM) groups*

	Baseline (0 weeks)		Mid-test (6 weeks)		Post-intervention (12 weeks)		Adjusted change 0-6 (95% CI) **	Adjusted change 0-12 (95% CI) **
(min·h^{-1})	jOG	COM	jOG	COM	jOG	COM		
Sedentary	39.3	38.9	39.6	38.5	38.5	37.7	0.7 (-0.7 to 2.1)	0.4 (-1.1 to 1.9)
	(3.9)	(3.2)	(3.5)	(2.7)	(3.5)	(3.1)		
$PA_{<4}$	13.6	14.0	13.5	13.8	13.5	14.1	0.3 (-1.0 to 1.6)	0.2 (-1.3 to 1.7)
	(2.9)	(2.8)	(3.4)	(3.0)	(3.3)	(3.6)		
$PA_{4-7.99}$	6.3	6.1	6.1	6.8	6.8	7.1	-0.9 (-2.1 to 0.3)	-0.8 (-2.3 to 0.7)
	(2.5)	(3.2)	(2.3)	(2.8)	(2.9)	(2.7)		
$PA_{\geq 8}$	0.8	1.0	0.8	0.9	1.2	1.1	-0.0 (-0.3 to 0.3)	0.1 (-0.3 to 0.6)
	(0.6)	(1.1)	(0.6)	(0.8)	(0.8)	(0.8)		
$PA_{\geq 4}$	7.1	7.0	7.0	7.7	7.9	8.2	-0.9 (-2.2 to 0.4)	-0.6 (-2.2 to 1.0)
	(2.4)	(3.4)	(2.3)	(3.0)	(3.1)	(2.9)		
TPA	20.7	21.1	20.4	21.5	21.5	22.3	-0.7 (-2.2 to 0.7)	-0.4 (-1.9 to 1.1)
	(3.9)	(3.2)	(3.5)	(2.8)	(3.5)	(3.1)		
Steps	805.6	768.4	790.3	841.6	867.1	935.2	-58.1 (-159.1 to 42.9)	-85.5 (-183.2 to 12.3)
(steps·h^{-1})	(191.7)	(160.1)	(177.7)	(195.6)	(193.8)	(178.5)		
CPM	556.5	562.2	526.4	592.7	619.2	663.2	-57.6 (-123.5 to 8.4)	-50.4 (-186.1 to 85.3)
	(151.2)	(148.1)	(114.7)	(145.9)	(205.3)	(242.2)		

* Baseline, mid-test and post-intervention values are unadjusted mean (SD).
** Change scores and 95% confidence intervals (CIs) are the differences between groups (relative to COM) after adjustment by ANCOVA for the baseline value and gender. ANCOVA for $PA_{<4}$, $PA_{4-7.99}$, $PA_{>4}$, steps and CPM at 12 weeks are also adjusted for change in maturation offset (post minus baseline).

PA, physical activity; TPA, total physical activity ($PA_{<4}$, $PA_{\geq 4}$), CPM, counts per minute.

6.3.3 Behaviour preferences

Self-reported behaviour measures are presented in Table 6.2. Both groups spent similar ($p > 0.05$) amounts of time in the assessed behaviours at baseline. Step-powered video gaming was significantly greater at week 6 than 12 in the jOG group. A statistically significant increase in active video gaming at 6 weeks was observed in the jOG group compared to the COM group. There were no other statistically significant intervention effects on behaviour variables. For active video gaming at 6 and 12 weeks, the mean difference in change score between groups satisfied criteria (0.14 $h \cdot d^{-1}$ increase: benefit) for the smallest clinically worthwhile effect. The mean difference in change score at 6 weeks between groups for inactive video gaming satisfied MCID criteria (0.25 $h \cdot d^{-1}$ decrease) for benefit, though the 12-week change score met this criterion in the opposite direction (detriment). Mean differences in change score for total video gaming at 6 and 12 weeks between groups satisfied MCID criteria for detriment (0.25 $h \cdot d^{-1}$ increase), as did the change score for leisure behaviours at 6 weeks (0.60 $h \cdot d^{-1}$ increase). The mean difference in change score for TV viewing between groups at 12 weeks satisfied criteria for benefit (0.37 $h \cdot d^{-1}$ decrease).

Table 6.2 Behaviour variable values for the intervention (jOG) and comparison (COM) groups*

	Baseline (0 weeks)		Mid-test (6 weeks)		Post-intervention (12 weeks)		Adjusted change 0-6 (95% CI) **	Adjusted change 0-12 (95% CI) **
($h \cdot d^{-1}$)	jOG	COM	jOG	COM	jOG	COM		
Inactive video gaming	2.84 (1.05)	2.56 (1.47)	1.37 (1.39)	1.78 (1.56)	1.98 (1.43)	1.86 (1.09)	-0.34 (-1.24 to 0.56)	0.37 (-0.32 to 1.05)
Step-powered jOG gaming	-	-	0.75 (0.71)	-	0.38 (0.55)†	-	-	-
Active video gaming	0.71 (0.75)	0.97 (0.59)	1.50 (1.53)	0.79 (0.69)	0.89 (1.16)	0.71 (0.65)	0.95 (0.25 to 1.65)‡	0.46 (-0.04 to 0.95)
Total video gaming	3.57 (1.12)	3.51 (1.46)	2.94 (2.01)	2.56 (1.72)	2.86 (1.76)	2.56 (1.35)	0.55 (-0.60 to 1.70)	0.62 (-0.18 to 1.41)
TV viewing	2.58 (1.68)	2.85 (2.10)	2.18 (1.74)	2.41 (1.89)	1.44 (1.17)	2.26 (1.78)	-0.15 (-1.10 to 0.79)	-0.71 (-1.58 to 0.15)
Productive behaviours	1.21 (1.10)	1.81 (1.57)	0.61 (0.57)	0.81 (0.78)	0.65 (0.36)	0.67 (0.46)	-0.15 (-0.59 to 0.28)	-0.04 (-0.30 to 0.21)
Leisure behaviours	7.04 (2.70)	6.98 (3.34)	6.21 (3.21)	5.16 (3.11)	4.55 (2.21)	5.10 (2.10)	0.66 (-1.39 to 2.71)	-0.23 (-1.43 to 0.97)

* Baseline, mid-test and post-intervention values are unadjusted mean (SD).
** Change scores and 95% confidence intervals (CIs) are the differences between groups (relative to COM) after adjustment by ANCOVA for the baseline value and gender.
† $p = 0.01$ (different from mid-test).
‡ Significant ($p < 0.01$).
Productive behaviours (reading for pleasure, doing homework, working on a computer); Leisure behaviours (TV viewing, total video gaming, computer/internet use for pleasure).

6.3.4 Anthropometrics and body fat

Table 6.3 presents anthropometric and body fat values. At baseline groups were comparable ($p > 0.05$) in body mass, BMI, and, subtotal and trunk body fat percentage, but stature was significantly greater in the COM group. Body mass expectedly increased in both groups across the trial. Compared with the COM group, the jOG group had a statistically significant increase in stature at 6 weeks. No other significant or clinically relevant changes were observed.

Table 6.3 Anthropometric and body fat values for the intervention (jOG) and comparison (COM) groups*

	Baseline (0 weeks)		Mid-test (6 weeks)		Post-intervention (12 weeks)		Adjusted change 0-6 (95% CI) **	Adjusted change 0-12 (95% CI) **
	jOG	COM	jOG	COM	jOG	COM		
Body mass	34.1	38.0	34.6	38.7	35.3	39.0	-0.2 (-0.9 to 0.5)	0.2 (-0.8 to 1.2)
(kg)	(10.0)	(10.6)	(10.2)	(10.6)	(10.4)	(10.6)		
Stature	**1.34**	1.38	1.35	1.39	1.36	1.40	**0.005 (0.001 to**	0.003 (-0.002 to
(m)	**(0.06)†**	(0.05)	(0.06)	(0.06)	(0.06)	(0.06)	**0.009) ‡**	0.009)
BMI	18.9	19.7	18.8	19.9	18.9	19.7	-0.2 (-0.6 to 0.2)	0.0 (-0.5 to 0.5)
($kg{\cdot}m^{-2}$)	(4.5)	(4.3)	(4.5)	(4.3)	(4.6)	(4.2)		
Subtotal body	26.7	27.2	26.7	27.4	27.1	27.2	-0.1 (-0.7 to 0.6)	0.6 (-0.4 to 1.5)
fat (%)	(9.4)	(9.0)	(9.6)	(9.1)	(9.7)	(9.2)		
Trunk body	20.7	21.9	20.8	21.8	21.4	22.1	0.5 (-0.6 to 1.6)	0.9 (-0.5 to 2.3)
fat (%)	(8.8)	(8.3)	(9.2)	(8.4)	(9.8)	(9.1)		

* Baseline, mid-test and post-intervention values are unadjusted mean (SD).
** Change scores and 95% confidence intervals (CIs) are the differences between groups (relative to COM) after adjustment by ANCOVA for the baseline value and gender. ANCOVA for trunk body fat % and subtotal body fat % at 12 weeks are also adjusted for change in maturation offset (post minus baseline).
† $p = 0.01$ (different from COM).
‡ Significant ($p = 0.02$). 3 decimal places reported to improve interpretation of ANCOVA.
BMI, body mass index.

6.4 Discussion

This RCT examined the short-term effects of a peripheral active video gaming device (jOG) on habitual PA and sedentary time, behaviour preferences and body fat in 8-10 year old children. Compared with an aged-matched comparison group, the intervention group had no statistically significant change in habitual PA (CPM) at 6 or 12 weeks. MCID analyses suggested however that relative to the comparison group, the intervention group had non-significant but detrimental changes in CPM, steps, $PA_{4\text{-}7.99}$ and $PA_{\geq 4}$ at 6 and 12 weeks. At 6 weeks, self-reported sedentary video game time decreased and active video game time significantly increased in the intervention group relative to the comparison group, with the increase in active gaming largely due to the use of jOG. However, overall time spent playing video games increased. At 12 weeks an overall increase in total video gaming was also observed relative to the comparison group. This was due to an increase in sedentary and active video gaming. Thus, given participants were randomised at the individual level and groups were comparable at baseline, these findings may suggest that an increase in time spent playing video games is detrimental to PA, regardless of whether the main contributor is active, or active and sedentary gaming. It should be acknowledged that sample size calculations were not conducted prospectively for the trial. Thus, the trial may have been insufficiently powered to detect significant effect sizes for PA variables that were practically different between groups, based on MCID analyses.

In a previous home-based active video game intervention, a similar trend for reduced self-reported sedentary video game time and increased active video game time has been observed in children (Ni Mhurchu et al., 2008). Maloney et al. (2008) also found children provided with a dance video game to self-report playing the game for a mean 60 $min \cdot wk^{-1}$ after 10 weeks, whilst self-reported sedentary screen time significantly decreased compared to controls. Taken together with findings from this trial therefore, provision of a peripheral device or active video game encourages children to experiment with the device and devote time away from sedentary screen-based activities. However, no positive effect on PA or sedentary time has been observed in any intervention.

In the present trial there were no significant differences between groups at 6 weeks for TV viewing, reading, doing homework or working on a computer. However, time spent in leisure behaviours (TV, total video gaming, computer/internet use for pleasure) increased relative to the comparison group, and although not significantly, MCID analysis suggested the change was detrimental. The adjusted change in TV viewing for the jOG group relative to the comparison group was negative, and increased total video gaming time was due to increased active gaming in the jOG group. Subsequent analysis indicated that computer/internet use for pleasure increased in the jOG group compared to the comparison group by 0.3 (95% CIs: -0.4 to 1.1) $h \cdot d^{-1}$ at 6 weeks. This may suggest that non-significant differences in objectively measured sedentary time were due to intervention children allocating more time to this alternative sedentary pursuit, though it is acknowledged that children may have reallocated time to other sedentary behaviours not assessed in the trial. If active video games are to increase habitual PA and reduce sedentary time, interventions may need to consider other concurrently available sedentary behaviours young people enjoy.

This idea is somewhat supported by mechanisms underpinning behaviour change. In PA promotion interventions, attempts are rarely made to modify access to competing behaviours, such as sedentary pursuits. However, behavioural economic theory suggests that by changing access to a competing class of behaviours (e.g. sedentary video gaming, TV, computer/internet use), the targeted behaviour (e.g. active video gaming, overall PA) is modified, even if the substitute behaviour (i.e. PA) is never directly enforced (Hursch and Bauman, 1987). This is supported by research indicating that reducing access to sedentary behaviours results in children choosing more active alternatives (Epstein et al., 1995). Video game based, environmental strategies in the home, may be more effective if access to sedentary video games is reduced and opportunities for active video gaming are provided, rather than solely enabling active gaming through equipment provision. This would relate to concepts of control and choice, whereby reinforcing a reduction in sedentary behaviour provides young people with the opportunity to choose how to allocate their newly available time. This opportunity to choose among alternatives is reinforcing, as the individual is more likely to pick an activity they want to do as they are in control, which increases the reinforcing value of the substitute behaviour (Rodin, 1986). With respect to previous literature however, reducing access to sedentary screen-based behaviours has been met with resistance and may not be a long-term solution (Faith et al., 2001; Wilson, 2007). Thus, the key for PA promotion may be to ensure that of the activities young people can choose from, the physically active behaviours (e.g. active video gaming, PA away from the screen) are more enjoyable than alternative sedentary behaviours. Future research is warranted to test alternative environmental strategies in the home, such as offering active video game and/or PA opportunities away from the screen that are more enjoyable than sedentary alternatives, and/or introducing child-friendly strategies in the home to reduce access to competing sedentary behaviours.

Self-reported use of the jOG system at 12 weeks was half that self-reported at 6 weeks. This decrease is indicative of a novelty effect previously observed in related interventions (Chin A Paw et al., 2007; Madsen et al., 2007; Maloney et al., 2008). In these studies, participants reported boredom with a dance simulation game as a key reason for reduced use over time (Chin A Paw et al., 2007; Madsen et al., 2007). In the present study, jOG was compatible with multiple video games children owned, which likely minimised the influence of over-familiarisation with a single game.

Children's motivation to play PS video games they owned may have decreased across the intervention. Though they may have played these games actively with jOG, this could have contributed to the self-reported decline in jOG use. If the case, this would suggest that though the use of jOG may be perceived as worthwhile, the video games children own also need to be changed to maintain interest. Contrary to this however, self-reported sedentary video gaming increased in the jOG group from 6 to 12 weeks as step-powered gaming declined. It is acknowledged that the increase in sedentary video gaming at 12 weeks may be due to an increase in the time spent playing games on other consoles. Data to confirm this was not collected however, and highlights that future trials investigating video game preferences should assess the time young people devote to particular consoles.

The physical nature of step-powered gaming may have contributed to the decrease in jOG use over time. Gaming with jOG requires continual stepping to activate the console controller, thus physical feedback from the working muscles is inherent.

Physical feedback such as manipulating a joystick was reported by adolescents and adults to act as a 'reality check' during video gaming that distracted them from the game (Wood et al., 2004). This characteristic of video games reminded the gamer of their physical surroundings (Wood et al., 2004) and prevented immersion (deep involvement) in the game and concomitant sensations of time loss (Wood et al., 2007). Escapism through gaming encourages people to play video games (Wood et al., 2007). Thus, step-powered gaming may have been distractive and felt like exercise over time for children, with physical sensations overriding enjoyment of the game. It is also possible that children were physically incapable of sustaining the level of stepping required. These factors may have reduced the perceived value of step-powered gaming, with sedentary gaming the more reinforcing alternative and preferred choice (Epstein et al., 2007). This is supported by the decrease in sedentary video gaming time at 6 weeks in the jOG group, and subsequent increase at 12 weeks when jOG use declined. Achieving an optimal balance between physical feedback and immersion may be important if active video games are to be enjoyed, valued and become the preferred choice over sedentary equivalents (Epstein et al., 2007).

No significant or clinically important intervention effects were observed for BMI and subtotal or trunk body fat across the trial. Maloney et al. (2008) similarly found no between-group change in BMI, systolic and diastolic blood pressure or pulse rate after 10 weeks intervention. In contrast, Ni Mhurchu et al. (2008) observed positive reductions in waist circumference for intervention children compared to controls at 12 weeks. However, the study was not adequately powered to detect differences in anthropometric variables (Ni Mhurchu et al., 2008), and like the present study failed to monitor energy intake changes across the trial. Energy intake is a key mechanism by which screen time contributes to obesity (Robinson, 1999) and may have confounded body composition findings. Thus, future screen-based interventions should account for changes in energy intake across the trial.

This study had several limitations. Similar to previous trials the sample size was small and intervention short (Chin A Paw et al., 2007; Maloney et al., 2008; Ni Mhurchu et al., 2008). Small samples are likely underpowered to detect changes in outcomes such as BMI or body fat. Twelve-week trials provide an indication of short-term behaviour change and do not address long-term sustainability. Future studies, such as that of Maddison et al. (2009) must address these issues to more definitively determine the impact of active video games on children's PA and health. This study was limited by the exclusion of 16 children based on insufficient PA data. However, non-significant differences at baseline for all variables between compliers and non-compliers suggest the discarded cases form a representative portion of the entire dataset and case deletion is a reasonable approach (Schafer, 1999). Only twenty-nine of the forty-two participants providing valid data had ≥ 1 weekend day at each time point. However, no significant differences were observed for PA variables at any time point between children providing 3 days of recording (with no weekend day) and 4, 5, 6 or 7 days of recording (one-way between groups ANOVA; data not shown), supporting the minimum inclusion criteria of any 3 days. Factors that may have influenced activity counts generated during the laboratory-based treadmill protocol across measurement periods include accelerometer positioning or technical issues with accelerometers (Jago et al., 2007). However, these were protected against as best as possible by the same researcher conducting all protocols and the same monitor being used for each protocol.

Though reliable and valid, the self-report method used to assess behaviour preferences may have been influenced by social demands and biases, and poor child recall of previous activity (Welk, 2002). An objective measure of sedentary time was obtained through accelerometry; however this gave no information on the type of behaviours performed. Objective measures such as direct observation can advance the field by providing behaviour assessments in an individual's day-to-day environment (Hartman and Wood, 1990). However, despite the availability of observation systems for recording children's behaviours in the home (McIver et al., 2009), application of this method requires extensive researcher training, is time-consuming and may be socially unacceptable (McKenzie, 2002). The use of video game memory cards and video game console hard drives could provide objective information on the duration and type of video games played, which might be an opportunity for future research.

Due to limited resources participants were not blind to researchers, which may bias effects observed (Hopkins et al., 2009). Although children were randomised at the individual level, some attended the same schools, with a contamination effect potentially influencing findings. The study used the PS compatible jOG system, with trials on the Wii compatible system or both systems warranted to examine effects across different consoles and games. Children were encouraged to play their video games with jOG in a step-powered manner. However, jOG includes an option that allows the user to enable and disable the device, and thus play video games seated without stepping whilst the device is connected to the console. Though children were instructed to self-report the time they spent playing video games with jOG in only a step-powered manner, it is possible that children included in this estimate time spent playing seated whilst the jOG was still connected. Lastly, qualitative data on children's perception of jOG may have provided an insight into why the device was or was not used, and highlights an important area for future research to consider.

6.5 Conclusion and future research

Children provided with a peripheral device designed to encourage step-powered video gaming in the home had increased self-reported active video gaming time and decreased sedentary video gaming time compared to a comparison group after 6 weeks. However, an associated decrease in sedentary time or increase in habitual PA was not observed relative to the comparison group. Conversely, detrimental changes in PA were found. Detrimental changes in PA were also evident at 12 weeks when overall video gaming increased relative to the comparison group, due to increased sedentary and active gaming. Thus, these findings may suggest that an increase in overall video gaming, due to active, or active and sedentary gaming, may be detrimental to PA in children. Behaviour preference data at 6 weeks suggested that intervention children may have allocated more time to an alternative sedentary behaviour. Therefore, reducing access to competing sedentary behaviours and/or offering active video game and/or PA opportunities away from the screen that are more enjoyable than sedentary alternatives over time may be important if active video gaming is to benefit children's habitual PA and health.

The decrease in use of the peripheral device from 6 to 12 weeks was indicative of a novelty effect similarly observed in related studies, and supports the call for the production of new active video games that attract children and sustain their interest (Pate, 2008). Reduced motivation to use jOG may have been due to boredom with currently owned video games. Conversely, physical feedback from continuously stepping on the spot may have prevented immersion in the game and increased participant's motivation to play video games in a sedentary manner. Achieving an optimal balance between physical feedback and immersion may be important if active video games are to be enjoyed, valued and become the preferred choice over sedentary equivalents.

Interventions of longer duration and in larger samples are needed to verify the long-term effect of active video gaming on PA and health. Trials should obtain information on the time young people allocate to multiple sedentary behaviours, including the time devoted to different video game consoles. Collecting this data through objective methods would be optimal, though the limited applicability of methods such as direct observation may inhibit this. Parent and child reports of time spent in various behaviours may provide a better assessment of the type, frequency and duration of behaviours young people participate in. Process evaluation should be included in a study design to obtain child and parent views on the device being provided. This will improve our understanding of an interventions success and inform future research. Accounting for changes in energy intake by assessing dietary intake throughout a trial is important; in order to better understand the mechanisms that contribute to any change in body composition.

6.6 Acknowledgements

Thanks to the pupils for their participation and Jennifer Cain, Kate Eccles, Richard Yarwood, Craig Davies and James Byrne for assisting data collection. Thanks to New Concept Gaming Co Ltd (Liverpool) for equipment support.

Chapter 7

Synthesis section

Synthesis section

7.1 Synthesis

In this synthesis results from the four studies and their implications will be discussed in relation to major themes in the thesis. The themes include the effect of active video games on PA, sedentary behaviour and health in young people, how PA and sedentary behaviour are measured, and behaviour change.

This thesis investigated whether active video games increased PA, reduced sedentary behaviour, and improved health in young people. Active video games were investigated to see if they encouraged PA and reduced time spent sitting (sedentary) compared to sedentary video games. Increasing PA and reducing sedentary time in young people are important as clustered metabolic risk is negatively associated with PA and positively associated with sedentary time in youth (Ekelund et al., 2007). Increasing total PA may also help regulate weight gain in young people, as has been shown in adults (Levine, 2007).

The studies within this thesis were based on Welk's (1999) YPAP model. The model provided a bottom-up framework that included demographic, enabling, predisposing and reinforcing factors, all deemed to influence youth PA (Welk, 1999). In the three laboratory-based studies, participants were provided with the opportunity to play active video games (enabling factor) and the PA and EE levels during active video gaming were measured using a variety of methods. Physical activity and EE levels for active video gaming were then compared to those measured during sedentary video gaming, authentic versions of the games played, and, brisk treadmill walking and treadmill jogging in study three. In the intervention study, children were provided with a peripheral device (jOG) that enabled active video gaming in the home (enabling factor). The intervention effect on habitual PA and sedentary time was objectively measured by accelerometers. Participants in the intervention were targeted based on SES, which is associated with screen time in Liverpool school children (Fairclough et al., 2009).

In studies three and four, enjoyment of active video gaming was also measured. Study three used a short version of the PACES to measure the enjoyment level of young people playing active video games after a short bout of play in a laboratory. Study four used a self-report survey to measure the amount of time young people spent playing active video games, and other behaviours, after provision of the jOG device. These measures provided an indication as to whether young people viewed active video gaming as a worthwhile pursuit to engage in, and whether active video games could change behaviour. This linked to the predisposing factors for PA engagement of 'am i able [to participate in active video gaming]' and 'is it [participation in active video gaming] worth it' (Welk, 1999).

A major theme in the thesis was how PA and sedentary behaviour were assessed. Across the four studies various measurement methods were used. This included the IDEEA system, portable indirect calorimetry, HR monitoring, and, high frequency accelerometry. Reliance on the IDEEA system to predict EE in study one was enforced by malfunctions with the portable indirect calorimetry system. Use of the IDEEA was deemed a limitation, as the system was not sensitive enough to detect upper limb movements that were primarily encouraged during play on Wii Sports bowling, tennis and boxing. A subsequent underestimation of EE for play on Wii Sports in study one was suggested. However, study two indicated that MET values for the same Wii Sports games were similar to study one. Moreover, in studies one, two and three, a consistent trend was observed for the energy cost of active video gaming compared to sedentary gaming, authentic versions of the sports, and, brisk treadmill walking and treadmill jogging. Therefore, the IDEEA system was suitable for assessing differences in EE between activities, and informing the key message that while active video games were not as costly in terms of EE as authentic PA, they were a better alternative than sedentary gaming for encouraging PA and reducing sedentary behaviour.

HR data from studies two and three, and accelerometry data from study two, indicated similar differences in PA between active and sedentary video gaming, authentic modes of the sports, and, brisk treadmill walking and treadmill jogging. For measuring differences in PA between various activities therefore, these methods were appropriate. If the aim was to accurately quantify the EE of a variety of sedentary and physical activities, indirect calorimetry should be used as the gold standard method. However, due to equipment cost and the feasibility of its use, this was only applicable for measurement over short periods and typically in laboratory settings. With this in mind, the research programme ultimately sought to assess the impact of active video gaming on habitual PA and sedentary behaviour in young people. Thus, use of indirect calorimetry to measure free-living PA in a larger sample was not suitable. The doubly labelled water method is precise for estimating total EE in free-living (Speakman, 1997). However, the method does not provide information on the time spent sedentary and in different intensities of PA (Ekelund et al., 2003). Accelerometers provide accurate and reliable information on the volume and intensity of habitual PA and the volume of sedentary behaviour in children and adolescents (Ward et al., 2005; Rowlands, 2007). Therefore, accelerometers were used to measure PA and sedentary time across the intervention study.

The decision to assess habitual PA and sedentary time with hip-mounted accelerometers in the intervention was supported by its previous validation for measuring free-living PA in youth (Ekelund et al., 2001). Findings from study two of the thesis provided further support for the use of hip-mounted accelerometers. Compared to an accelerometer placed on the wrist and HR monitoring, an accelerometer placed on the hip was the best single measure for explaining the variance in assessed EE during active video gaming on Wii Sports in adolescents. This was despite the games being non-ambulatory and primarily encouraging upper limb movements, which were not detected by hip-mounted accelerometers.

Interestingly, the study found that the variance explained in EE during active video gaming improved when data from two PA measurement devices was combined, in comparison to each device used in isolation. The combination of measurement devices was HR monitoring and a hip-mounted accelerometer, and, a hip and wrist-mounted accelerometer. For the combination of a hip and wrist-mounted accelerometer, the findings contrasted previous research in adults that reported little improvement in the explained variance in EE when adding wrist accelerometer data to hip accelerometer data (Kumahara et al., 2004; Swartz et al., 2000). Young people are likely to participate in several non-ambulatory activities during a day that encourage activity-related EE from the upper limbs (Eston et al., 1998; Vandewater et al., 2006). Thus, research is warranted to confirm these findings in youth of varying age, across different activities, and during free-living. For the combination of HR monitoring and hip-mounted accelerometer data, findings were similar to those previously reported in young people and adults (Brage et al., 2007; Corder et al., 2005; Corder et al., 2007b). However, to date these findings are limited to laboratory or field-based studies assessing specific activities over short periods. Before this combined measurement approach is used to assess habitual PA and EE in young people, research is needed to demonstrate that this method maintains greater accuracy than either device used in isolation in free-living situations (Corder et al., 2005).

In the intervention study, habitual PA data from the hip-mounted accelerometers was analysed using an individual calibration approach. This approach contrasts a wide range of studies that typically analyse habitual PA data for a sample with a generic set of activity count thresholds generated from validation studies. A generic approach was not used as there is great variation in the range of activity count thresholds (Guinhouya et al., 2006; Rowlands, 2007). This range of thresholds has made between-study comparisons in the literature difficult. Further, the range of thresholds have provided mixed messages surrounding the prevalence of PA and sedentary behaviour in young people (Mota et al., 2007; Reilly et al., 2008), and influenced understanding of the dose response relationship between PA and health outcomes, as well as the effectiveness of interventions (Corder et al., 2007a; Jago et al., 2007).

An individual calibration approach may be a solution to the problems generated by the range of activity count thresholds, as it enables researchers to avoid the dilemma of having to choose which set of thresholds to apply to PA data. This would only serve to advance the field of PA research if all groups adopted the same approach. To achieve this, a standard set of reference exercises would need to be formulated, agreed upon between research groups and implemented consistently across research designs. Most daily PA is accumulated through walking and jogging, so it is logical that these activities should be the reference exercises used in calibration protocols. An example is walking at 4 $km \cdot h^{-1}$ (Ekelund et al., 2003), as used in this thesis. It is acknowledged that a standard individual calibration approach would be time intensive for participants and lengthen the analysis process for researchers compared to use of generic thresholds. However, unless new approaches such as this are adopted, problems resulting from the great variation in the range of activity count thresholds, such as the uncertainty over the prevalence of PA and sedentary behaviour in youth, will not be solved. A standard individual calibration protocol should also use high frequency PA monitoring (5-s epochs) to generate activity count thresholds. These thresholds can then be used to assess habitual PA data that was similarly measured in 5-s epochs. This will reduce the underestimation of moderate and vigorous PA in children compared to use of 60-s epochs (Nilsson et al., 2002; Corder et al., 2007c).

From the intervention study in this thesis, an important issue relating to the analysis of habitual PA data was encountered. For a day that a participant wears an accelerometer to be included in data analysis, researchers typically set an inclusion criterion for wear/recording time. This has ranged from 8 to 10 $h{\cdot}d^{-1}$ (Rowlands, 2007). If above the inclusion criterion, the day is included. Absolute values of the time spent at various PA intensities are then usually reported, such as 60 $min{\cdot}d^{-1}$ in MVPA. However, study four indicated that participants providing different wear times over the criterion had statistically significant differences in sedentary time and time spent in $PA_{<4}$. For example, at baseline, participants providing $\geq$ 13.0 $h{\cdot}d^{-1}$ of valid mean recording times had greater sedentary time than those providing 10.0-10.9 $h{\cdot}d^{-1}$ and 11.0-11.9 $h{\cdot}d^{-1}$ of valid mean recording times. In cross-sectional analyses, the participants who provided $\geq$ 13.0 $h{\cdot}d^{-1}$ would be concluded to spend significantly more time sedentary than participants who provided 10.0-10.9 $h{\cdot}d^{-1}$ and 11.0-11.9 $h{\cdot}d^{-1}$. However, the difference in sedentary time may be due to participants wearing the monitor for longer and thus accumulating more sedentary time. If those who provided 10.0-10.9 $h{\cdot}d^{-1}$ and 11.0-11.9 $h{\cdot}d^{-1}$ of valid recordings wore the monitor for an extra 1-2 $h{\cdot}d^{-1}$, they may have accumulated an absolute amount of sedentary time similar to participants who wore the monitor for longer.

The influence that wear time can have on the interpretation of habitual PA data can be further illustrated using hypothetical intervention data. Imagine, at baseline, a participant provided 9 $h{\cdot}d^{-1}$ of valid recordings on 3 days, which was the minimal inclusion criterion. Each day the participant accumulated 50 mins of MVPA. Based on an absolute mean time spent in MVPA of 50 $min \cdot d^{-1}$, the participant was concluded to not meet the daily PA recommendations for young people. After a PA intervention, the participant provided 13 $h \cdot d^{-1}$ of valid recordings on 3 days, and accumulated 70 mins of MVPA each day. Based on an absolute mean time spent in MVPA (70 $min \cdot d^{-1}$), it was concluded that the participant met PA guidelines and the intervention was successful. However, when the absolute data were scaled for mean recording time, it became evident that the time the participant spent in MVPA had stayed constant from baseline (50 $min \cdot d^{-1}$ / 9 h = 5.6 $min \cdot h^{-1}$ registered time) to post intervention (70 $min \cdot d^{-1}$ / 13 h = 5.4 $min \cdot h^{-1}$ registered time). This illustrated that the results were influenced by wear time and the intervention was not as successful as first thought. In light of the chance that this analysis problem can influence the interpretation of habitual PA data, PA data in study four was adjusted for registered time. Future research should consider adopting this analysis approach to prevent the misinterpretation of habitual PA data.

In study four, the effect of the intervention on primary and secondary outcome variables was assessed using ANCOVA. ANCOVA is a null hypothesis test that represents a traditional approach to inferential statistics (Batterham and Hopkins, 2006). Use of null hypothesis testing has been criticised, as it provides an indication of whether there is ($p < 0.05$) or is not ($p > 0.05$) a worthwhile effect, and not an indication of the direction or size of the effect (Batterham and Hopkins, 2006). In light of this, effects observed from ANCOVA were evaluated for importance through pre-specification of a MCID. This analysis approach made inferences based on meaningful magnitudes (Hopkins et al., 2009).

The MCID analysis approach used in study four was basic, as an insight into the direction of the effect (beneficial, detrimental, trivial) was drawn (Batterham and Hopkins, 2006). Information on the size of the effect can be provided by calculating and interpreting the probability (percent chance) that the true population effect was trivial (within ± MCID), beneficial (>MCID) or detrimental (>MCID in opposite direction) (Batterham and Hopkins, 2006). Caution has been expressed about reporting the direction and size of the effect when there are more than a few outcome statistics, as this can produce a cluttered and confusing report (Batterham and Hopkins, 2006). Therefore, this study only reported the direction of the effect due to the large number of variables that were assessed. It is acknowledged that providing information on both direction and size of an effect is more content-rich than either used in isolation (Batterham and Hopkins, 2006). However, the analysis approach used in this study represented a progressive form of statistical analysis that Batterham and Hopkins (2006) state should be embraced compared to sole use of null hypothesis testing.

The overarching theme in the thesis was the effect of active video games on PA, sedentary behaviour and health in young people. In the three laboratory-based cross-sectional studies, play on games and exercises on the active video games Wii Sports and Wii Fit, respectively, was found to increase PA and EE to light and moderate intensities in young people aged between 11 and 17 years. The increase in multiples of EE above values recorded during supine rest and sedentary video gaming was significant. Thus, active video games were concluded to increase PA and also contribute to reducing time spent sedentary. In study three, similar findings were observed for adults aged between 21 and 70 years. This supported the idea that active rather than sedentary video gaming should be promoted throughout the lifecourse.

The impact of increasing total PA on weight maintenance was supported by data from study two. The highest volume, video game playing adolescents in the UK accumulate approximately 14 $h \cdot wk^{-1}$ of sedentary video gaming (Pratchett, 2005). Based on the energy cost of the least intense active video game in study two, it was calculated that if this 14 $h \cdot wk^{-1}$ of sedentary gaming was converted to active gaming, an excess EE of 3514 $kJ \cdot wk^{-1}$ would result, if all other factors including energy intake remained constant. If sustained over time, this net increase in total PA and EE could result in an adolescent losing 1 kg of fat in approximately 8 weeks, if all other factors again remained constant. Given the current prevalence of overweight and obesity in contemporary youth (Stratton et al., 2007), these findings supported the promotion of active rather than sedentary video gaming as a mechanism for weight maintenance and loss.

The EE theme was explored further by comparing the energy cost of active video gaming with that reported for authentic versions of the games played (Ainsworth et al., 2000; Ridley et al., 2008), and, brisk treadmill walking and jogging in study three. It was clear that the PA and EE levels were significantly lower during active video gaming compared to authentic modes of PA and aerobic exercise. Active video games were typically of light intensity (< 3 METs), with only Wii Sports boxing and Wii Fit aerobics exercises of moderate intensity (3-6 METs). Therefore, the active video games were not as costly in terms of EE as the real thing. Moreover, only play on Wii Sports boxing and Wii Fit aerobics was intense enough to meet recommendations for health-enhancing PA in youth of 60 $min \cdot d^{-1}$ of MVPA (DH, 2004).

None of the active video games were found to be of sufficient intensity to promote cardiorespiratory fitness in adolescents. This was likely due to active video gaming being intermittent rather than continuous in nature. Active video games also required less whole body movement compared to authentic play. For example, in Wii Sports tennis participants did not have to move the point of ball contact, the computer did this automatically. Based on the definition of exercise therefore, this would suggest that repeated active video game play could not develop cardiorespiratory fitness. However, in addition to the metabolic health benefit of increasing total PA through active video gaming, repeated play on active video games may improve or develop other components of physical fitness, such as agility, balance, coordination, flexibility and reaction time. Future work in this field should develop the research paradigm to include performance measures of other components of physical fitness in order to better determine the potential benefits of active video games. This is particularly pertinent for studies using Wii Fit, which targets muscular strength and endurance, balance, coordination and flexibility.

In relation to the theme of behaviour change, results from study three suggested that adolescents, young adults and older adults enjoyed game play on all four Wii Fit activities. The enjoyment derived from handheld sedentary video gaming was significantly less than Wii Fit activities in adolescents and young adults. Greater enjoyment of Wii aerobics compared to treadmill exercise in adolescents also suggested that this population may be most receptive to advancing innovative technologies aiming to discourage sedentariness and increase PA through video gaming. Previous research has indicated that if given the choice, children are more motivated to play video games in an active rather than sedentary manner in a laboratory and home setting (Epstein et al., 2007; Mellecker et al., 2008). Thus, in the context of the YPAP model (Welk, 1999), these findings suggested that active video games were an enjoyable mode of entertainment that young people were able to engage in, and, perceived to be worthwhile engaging in. Whilst these findings were encouraging for the potential influence of active video games on behaviour change, they were limited to short bouts of gaming. Longitudinal studies were needed to determine if enjoyment of/engagement with active video gaming was maintained over time, or there was a novelty effect.

To achieve this, participants in study four were required to recall and report the amount of time they spent engaged in various activities, including active video gaming, for a typical weekday and weekend day. Using self-report methods in children aged 8 to 10 years has been debated, as the data may have been influenced by social demands and bias, and poor recall (Welk, 2002). However, the self-report method was selected as it has been shown to be reliable in a large sample of children aged 7 to 12 years (Laurson et al., 2008) and demonstrate appropriate predictive validity, albeit in adolescents (Gentile et al., 2004). Moreover, the method was easy and cheap to administer to a sample this size, and allowed data to be collected for weekdays and weekend days. Collecting data separately for weekdays and weekends days acknowledged the known differences across these periods for time spent with screen-based media (Vandewater et al., 2006).

Through this study, the experience gained of measuring the time young people spend with screen-based media led to suggestions that future research should seek to use technology to obtain objective measures of the frequency and duration of media use. A potential approach is to use devices such as video game memory cards, and hard drives that are built into video game consoles. These devices can record the duration and type of video games played. If these devices can be used successfully, they will avoid the limitations associated with self-report methods. They will also avoid limitations associated with the gold standard method for measuring time spent in various behaviours in the home, which is direct observation. Direct observation is limited by the need for extensive researcher training, the high burden placed on the researcher, the time-consuming nature of data collection, and the possible lack of social acceptability (McKenzie, 2002). The modification of available technologies to capture young people's engagement with screen-based media presents an opportunity and challenge for future research that would require collaboration between academic and industry professionals.

Data from the self-report survey used in the intervention indicated that at 6 weeks the intervention (jOG) group had a decrease in sedentary video game time, a significant increase in active video game time, and an increase in total video game time relative to the COM group. At 12 weeks an increase in total video gaming was also observed relative to the COM group, due to an increase in sedentary and active video gaming. However, at 6 and 12 weeks, the jOG group had no statistically significant change in habitual PA (CPM) compared with the COM group. Moreover, MCID analyses suggested that relative to the COM group, the jOG group had non-significant but detrimental changes in CPM, steps, $PA_{4\text{-}7.99}$ and $PA_{\geq 4}$ at 6 and 12 weeks. Thus, it was suggested that an increase in total video gaming may negatively affect habitual PA in children.

In previous active video game interventions, increased active video gaming and decreased sedentary video gaming have similarly had no positive effect on habitual PA or sedentary time in youth (Ni Mhurchu et al., 2008; Maloney et al., 2008). The question therefore is why this was the case. Study four attempted to address this by measuring the time children spent in other common behaviours. This was not considered in the trials of Ni Mhurchu et al. (2008) and Maloney et al. (2008), and was included based on suggestions that interventions targeting a specific behaviour should assess other behaviours youth engage in, in order to establish if compensatory changes in time spent in those behaviours occurs (Robinson, 1999).

Indeed, results suggested that a compensatory change may have occurred at 6 weeks, as the intervention group had a relative increase in the time spent using the computer/internet for pleasure compared to the COM group. Thus, though the intervention was seemingly successful at displacing sedentary video game time with active video game time, this may have inadvertently resulted in the displacement of time spent in other physical activities with computer/internet use. Consequently, this would help explain why no positive effect on objectively measured habitual PA or sedentary time was observed. Whilst the study design was acknowledged to be underpowered and thus generalisations could not be confidently made to the population, the findings suggested that the research design used was not successful.

The research design was based on the YPAP model (Welk, 1999). Therefore, the intervention findings suggested that in children from areas of low SES, increased habitual PA and reduced sedentary time were not achieved by simply enabling PA in the home through the provision of active video gaming equipment. More complex interventions including other opportunities to be active and/or reduce sedentary behaviour therefore seemed necessary in order to positively impact PA, sedentary behaviour and health. In future interventions solely focusing on active video games, attempts should be made to ensure that the games provided are more enjoyable than available sedentary behaviours in and around the home, and that this is the case over a sustained period. In addition, new active video games or graded increases in the difficulty of current games may need to be provided at regular intervals. This suggestion is supported by this thesis and previous studies (Chin A Paw et al., 2007; Madsen et al., 2007; Maloney et al., 2008) that have shown the time spent using active video games or peripheral devices to decrease across an intervention. Alternatively, new active video games that attract children and sustain their interest over time need to be produced by manufacturers (Pate, 2008).

If an intervention has the capacity to expand beyond the target behaviour of active video gaming, then other strategies in and around the home could be employed. Participants could be provided with PA opportunities away from the screen, in addition to active video games, that are also more enjoyable than sedentary alternatives. Conversely, interventions could limit access to competing sedentary behaviours in and around the home, such as TV viewing, sedentary video gaming or computer/internet use for pleasure. This approach should be used with caution however, based on reports that young people are resistant to relinquishing screen-based activities (Faith et al., 2001; Wilson, 2007) and the continual proliferation of screen-based technologies.

An important point to consider in any active video game-based intervention is the influence parents and sibling can have on the behaviour of the target child when in and around the home. Study four placed little emphasis on support from parents and siblings to encourage behaviour change. However, as suggested by the YPAP model, greater support from parents and siblings may reinforce the conversion of video gaming from sedentary to active over sustained periods. Reinforcement from parents and siblings can also encourage young people to spend more time in other physical activities, and less time in sedentary behaviours. If achieved, this could result in a targeted decrease in sedentary behaviour and increase in PA and EE, which would benefit the health of young people who spend as much as 14 $h \cdot wk^{-1}$ playing sedentary video games. Future trials should also incorporate a process evaluation into the study design, in order to tell which factors contribute to the intervention succeeding or failing. Change in energy intake across a screen-based intervention should also be measured, as this is a key mechanism by which screen time contributes to obesity (Robinson, 1999), and may influence any changes observed in body composition.

7.2 Summary

The studies within this thesis have provided an insight into the effect of active video games on the PA and EE levels of young people and adults. The home-based intervention investigated the effect of a peripheral device that enabled active video gaming on children's habitual PA and sedentary time, behaviour preferences and body composition. The findings from this thesis indicated that targeted changes in home-based video game use did not increase habitual PA or reduce sedentary time in children when compared to a comparison group. Rather than simply enabling PA by providing active video gaming equipment, more complex interventions that consider the range of PA and sedentary behaviour opportunities available to young people in the home environment appear necessary. Cross-sectional findings from this thesis indicated however that active video gaming had a positive effect on EE compared to sedentary equivalents in young people and adults. Thus, if complex interventions are successful at encouraging young people to sustainably convert video gaming from sedentary to active, whilst increasing PA away from the screen and preventing an increase in the time spent in alternative sedentary behaviours, then this is likely to have a positive effect on energy balance and health across the lifecourse.

Chapter 8

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Appendix 1

Study Related Documents

Video Gaming Experience Questionnaire (Chapters 3 and 4)

Faculty of Science

LIVERPOOL JOHN MOORES UNIVERSITY

GAMING EXPERIENCE QUESTIONNAIRE

NAME: ________________________________

DATE OF BIRTH: __ __/__ __/__ __ __ __

Circle the appropriate word/number, or tick the appropriate box(es)

1. Have you ever played video games?

YES / NO

2. How interested in video games are you?

NOT INTERESTED 1 2 3 4 5 VERY INTERESTED

3. Which of the following, if any, do you have?

- ☐ PC
- ☐ PS1
- ☐ X-Box
- ☐ N64
- ☐ GameBoy (and GB Advanced)
- ☐ PSP
- ☐ X-BOX 360
- ☐ Sega
- ☐ PS2
- ☐ DreamCast
- ☐ GameCube
- ☐ Nintendo DS
- ☐ Nintendo Wii

Other (please specify) ________________________________

4. How old were you when you played your first video game?

A. Before Nursery School (aged 3 years)
B. Nursery School (aged 3 – 6 years)
C. Reception to Year 1
D. Year 2 to Year 4
E. Year 5 to Year 6
F. Secondary School - Year 7-10
G. Secondary School - Year 11-12
H. Young Adulthood / Post Secondary School
I. Middle Adulthood (aged 30 to 50 years)
J. Late Adulthood (over 50)
K. Never played a video game

5. How many days in a week do you typically play video games?

A. Less than once a week
B. One
C. Two
D. Three
E. Four
F. Five
G. Six
H. Seven

6. If you typically play less than once a week, estimate how many times you play per month; otherwise go on to question 7?

A. Less than once a month
B. Once a month
C. Twice a month
D. Three times a month

7. How long is your typical playing session?

A. Less than 15 minutes
B. Greater than 15 minutes but less than an hour
C. One to two hours
D. Two to four hours
E. Four to six hours
F. Six to eight hours
G. Eight to 10 hours
H. Over 10 hours

8. What game do you play the most now? ______________________________

9. What game have you played the most? ______________________________

10. Name your five favourite games?

____

____

____

____

____

11. Which setting do you most typically play in?

A. Arcade
B. Home
C. Friends house
D. Computers in an Internet cafe/gaming store
E. Other (please specify) ____________________

12. Who do you typically play with?

A. Alone
B. Alone but on the internet or by modem with others
C. With a friend nearby who may or may not be playing but is involved in the activity to some extent

13. Do your parents/carer/guardian ever restrict your computer play – e.g. you can only play for a certain amount of time or you can only play on certain games?

YES / NO

If yes please specify

____
____
____
____

Thank you for completing this questionnaire

Exercises Completed on Wii Fit (Chapter 5)

Description of Wii Fit exercises

Training category Exercise	Description
Yoga poses	
Half moon	With both arms raised above the head, lean the upper body to the left and right sides and hold the stretch in time with the onscreen instructor.
Warrior	With one foot on the Balance Board and the other behind the Board, bend the leading knee and hold the stretch with outstretched arms in time with the onscreen instructor.
Tree	With the bottom of the foot on the inner thigh or calf, extend the arms up and stand straight, in time with the onscreen instructor.
Muscle conditioning	
Single-leg extension	With one foot on the Board and the other raised, extend the raised leg back and forth whilst reaching forward and back with the arm opposite to the raised leg in time with the onscreen instructor.
Trunk and waist twists	With arms outstretched, twist the trunk to the left and right, and, twist forward from the waist to the left and right in time with the onscreen instructor.
Lunge	With one foot on the Board and the other behind the Board, lower and raise the body by bending both knees in time with the onscreen instructor.
Balance games	
Ski slalom	Lean forward, backward, left and right to guide a character through gates down a course.
Heading	Lean left and right to head footballs and avoid other objects.
Balance bubble	Lean forward, backward, left and right to guide a character down a course, avoiding obstacles down the course.
Aerobic exercises	
Hula hoop	Swing the hips and lean left and right to rotate and collect hoops.
Step aerobics	Step on and off the Board to the back and sides in time with sensory instructions (visual and audio).
Jogging	Jog on the spot (on the floor not Board) at a self-selected speed with the Wii Remote held or placed in the trouser/short pocket.

Physical Activity Enjoyment Scales (PACES) shortened version (Chapter 5)

PACES items

Please rate how you feel *at the moment* about the physical activity you have been doing.

1	2	3	4	5	6	7
* I enjoy it						I hate it
1	2	3	4	5	6	7
I dislike it						I like it
1	2	3	4	5	6	7
It's no fun at all						It's a lot of fun
1	2	3	4	5	6	7
* I feel good physically while doing it						I feel bad physically while doing it
1	2	3	4	5	6	7
I am very frustrated by it						I am not at all frustrated by it

* Item is reverse scored, ie 1=7, 2=6, 3=5, 4=4, 5=3, 6=2, 7=1

Video Gaming Survey (Chapter 6)

CHILD VIDEO GAMING SURVEY

liverpool JMU

NAME: ____________________ DOB: __ __/__ __/__ __ __ __

PLEASE ANSWER THE FOLLOWING QUESTIONS
CIRCLE THE APPROPRIATE WORD/NUMBER, TICK THE APPROPRIATE BOX(ES) OR FILL IN THE BLANK SPACES

1. How interested in video games are you? (Please circle a number)

NOT INTERESTED 1 2 3 4 5 VERY INTERESTED

2. Which of the following do you have? (Please tick)

- ☐ Personal Computer (PC)
- ☐ PS1
- ☐ PS3
- ☐ X-BOX
- ☐ N64
- ☐ GameBoy (and GB Advanced)
- ☐ PSP
- ☐ A Sony EyeToy
- ☐ Sega
- ☐ PS2
- ☐ DreamCast
- ☐ X-BOX 360
- ☐ GameCube
- ☐ Nintendo DS
- ☐ Nintendo Wii
- ☐ A Dance Simulation Game

Other (please specify) ____________________

3. What video game do you play the most now? Please indicate which console you play this on.

____

4. What video game have you played the most? Please indicate which console this was played on.

____

5. Name your three favourite video games.

____________________ ____________________

____

If you have a PlayStation 2 or 3, please answer the following questions, if not skip to question 8 on the next page:

6. Please indicate how much time you spend in minutes sitting down playing video games on your PlayStation 2 or 3 during the three time periods: from waking until lunch, from lunch until dinner, from dinner until bedtime, **for a typical school day** (e.g. 60 minutes from dinner until bedtime)

Activity	From waking until lunch	From lunch until dinner	From dinner until bedtime
Playing inactive (seated) video games on your PlayStation 2 or 3			

7. Please indicate how much time you spend in minutes sitting down playing video games on your PlayStation 2 or 3 during the three time periods: from waking until lunch, from lunch until dinner, from dinner until bedtime, **for a typical weekend day** (e.g. 60 minutes from dinner until bedtime)

Activity	From waking until lunch	From lunch until dinner	From dinner until bedtime
Playing inactive (seated) video games on your PlayStation 2 or 3			

8. Please indicate how much time you spend in minutes in the following activities during the 3 time periods: from waking until lunch, from lunch until dinner, from dinner until bedtime, **for a typical school day** (e.g. 60 minutes from dinner until bedtime)

Activity	From waking until lunch	From lunch until dinner	From dinner until bedtime
Playing inactive (seated) video games on any console or PC			
Playing active video games (on your feet) on consoles like the Nintendo Wii, Sony EyeToy or Dance Mats or PC			

9. Please indicate how much time you spend in minutes in the following activities during the 3 time periods: from waking until lunch, from lunch until dinner, from dinner until bedtime, **for a typical weekend day** (e.g. 60 minutes from dinner until bedtime)

Activity	From waking until lunch	From lunch until dinner	From dinner until bedtime
Playing inactive (seated) video games on any console or PC			
Playing active video games (on your feet) on consoles like the Nintendo Wii, Sony EyeToy or Dance Mats or PC			

10. Which setting do you most typically play video games in? (Please circle)

A. Arcade
B. Home
C. Friends house
D. Computers in a gaming store
E. Other (please specify) ____________________

11. Who do you typically play with? (Please circle)

A. Alone
B. Alone but on the internet or by modem with others
C. With a friend nearby who may or may not be playing but is involved in the activity to some extent
D. With a sibling nearby who may or may not be playing but is involved in the activity to some extent
E. With a parent/carer/guardian nearby who may or may not be playing but is involved in the activity to some extent

12. Do your parents/carer/guardian ever restrict your computer play? E.g. you can only play for a certain amount of time or you can only play on certain games? (Please circle)

YES / NO

If yes please specify

____
____
____
____

Thank you for completing this survey

If you have any questions about filling this survey in please do not hesitate to contact **Lee on 0151 231 4436**

Dual-energy X-ray Absorptiometry Output Copy (Chapter 6)

Name: [redacted] Patient DOB: 07 August 1999	Sex: Male Ethnicity: White	Height: 126.3 cm Weight: 25.3 kg Age: 9

Referring Physician: LeeG

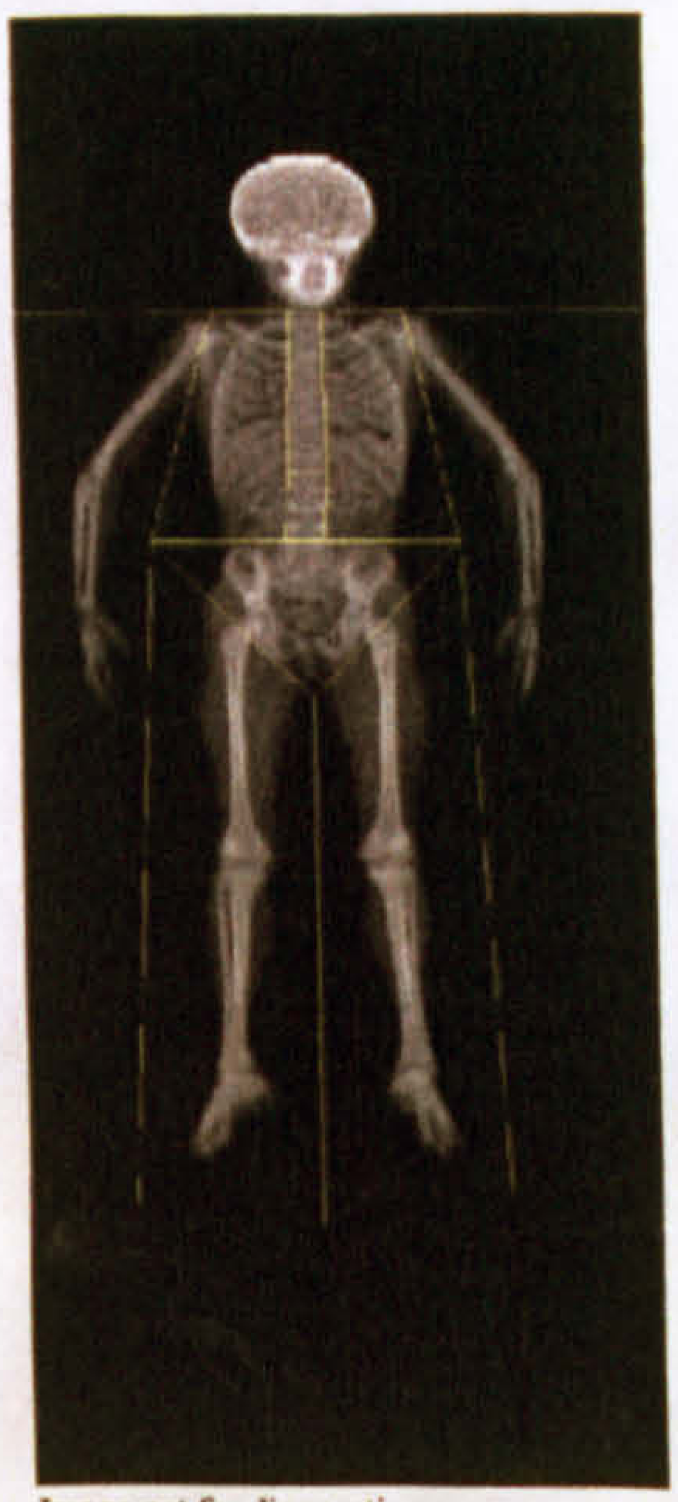
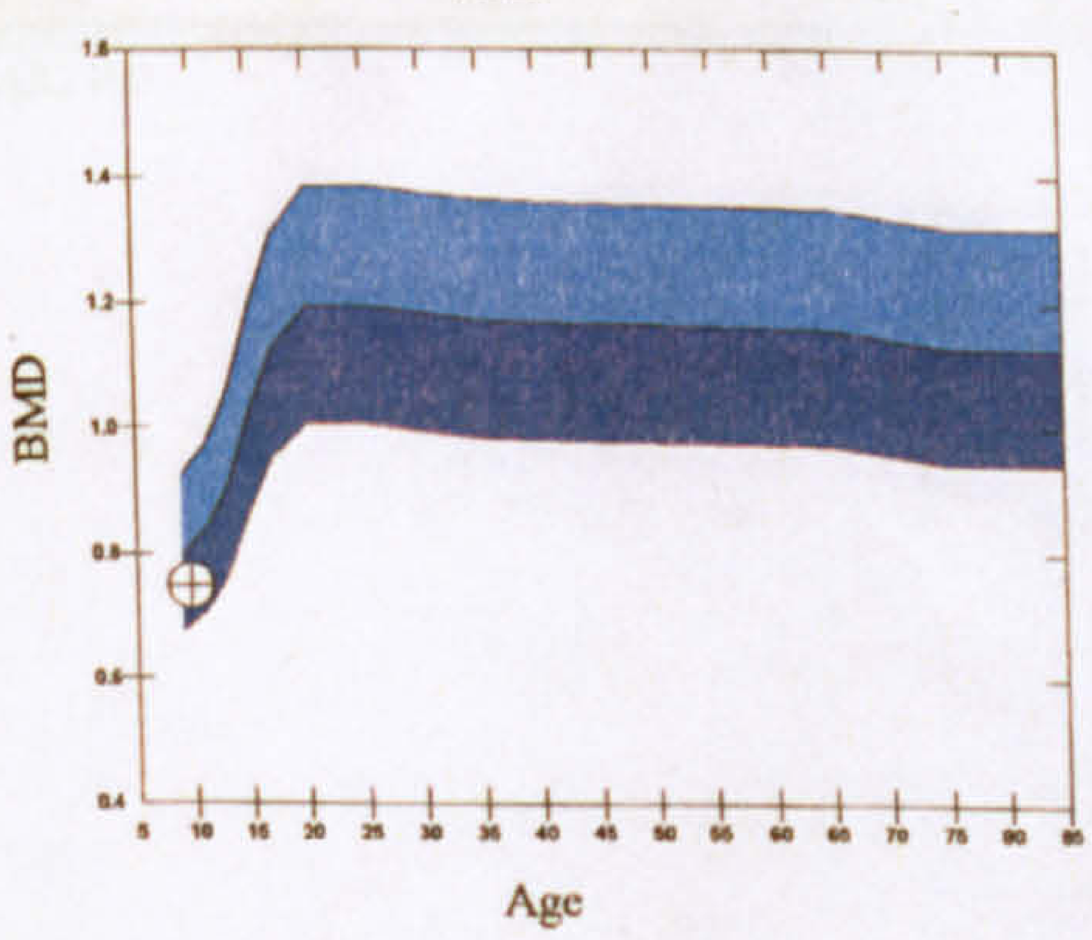


Image not for diagnostic use
k = 1.180, d0 = 50.5
327 x 150

Scan Information:

Scan Date: 02 April 2009 ID: A0402090B
Scan Type: a Whole Body
Analysis: 06 April 2009 13:58 Version 12.4:3
Auto Whole Body Fan Beam
Operator:
Model: Discovery A (S/N 70719)
Comment:

Total



Reference curve and scores matched to White Male

Source: Hologic

DXA Results Summary:

Region	Area (cm^2)	BMC (g)	BMD (g/cm^2)	T - Score	PR (%)	Z - Score	AM (%)
L Arm	101.72	49.15	0.483				
R Arm	113.79	53.98	0.474				
L Ribs	71.57	33.00	0.461				
R Ribs	73.98	31.56	0.427				
T Spine	63.53	31.53	0.496				
L Spine	32.57	18.63	0.572				
Pelvis	124.64	79.41	0.637				
L Leg	199.83	155.89	0.780				
R Leg	208.68	159.34	0.764				
Subtotal	990.31	612.49	0.618				
Head	229.99	298.19	1.297				
Total	**1220.30**	**910.68**	**0.746**		**63**	**-1.0**	**92**

Total BMD CV 1.0%, ACF = 1.033, BCF = 1.021

Physician's Comment:

HOLOGIC

Name: [redacted]
Patient [redacted]
DOB: 07 August 1999

Sex: Male
Ethnicity: White

Height: 126.3 cm
Weight: 25.3 kg
Age: 9

Scan Information:

Scan Date: 02 April 2009 ID: A0402090B
Scan Type: a Whole Body
Analysis: 06 April 2009 13:58 Version 12.4
Auto Whole Body Fan Beam
Operator:
Model: Discovery A (S/N 70719)
Comment:

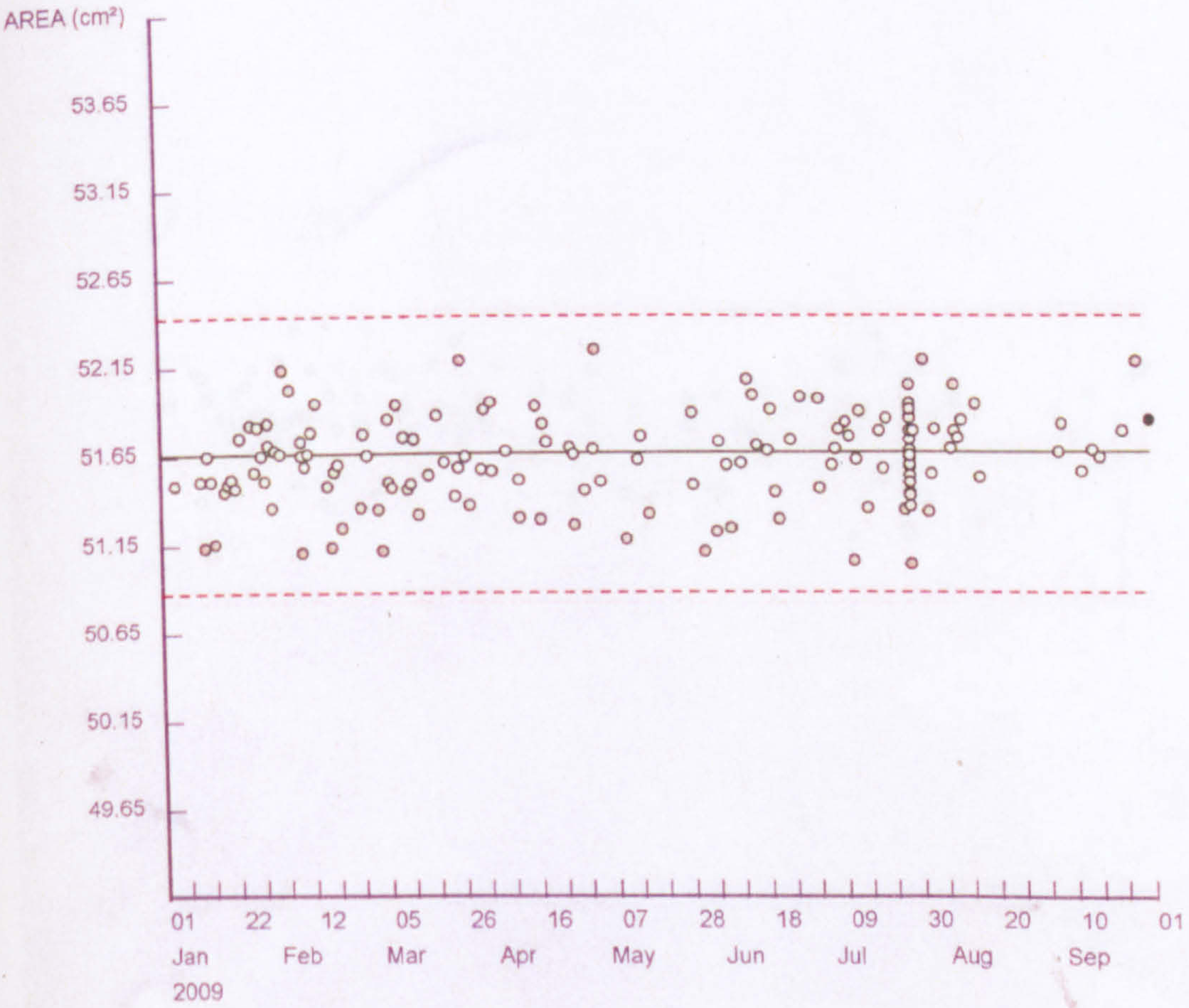
DXA Results Summary:

Region	BMC (g)	Fat (g)	Lean (g)	Lean+BMC (g)	Total Mass (g)	% Fat
L Arm	49.15	215.0	1030.9	1080.0	1295.0	16.6
R Arm	53.98	257.1	1034.9	1088.9	1345.9	19.1
Trunk	194.13	1075.3	9504.8	9698.9	10774.1	10.0
L Leg	155.89	1017.0	2913.7	3069.5	4086.5	24.9
R Leg	159.34	857.5	3122.5	3281.9	4139.4	20.7
Subtotal	612.49	3421.8	17606.7	18219.1	21641.0	15.8
Head	298.19	800.4	2804.6	3102.7	3903.1	20.5
Total	**910.68**	**4222.2**	**20411.2**	**21321.9**	**25544.1**	**16.5**

TBAR2460

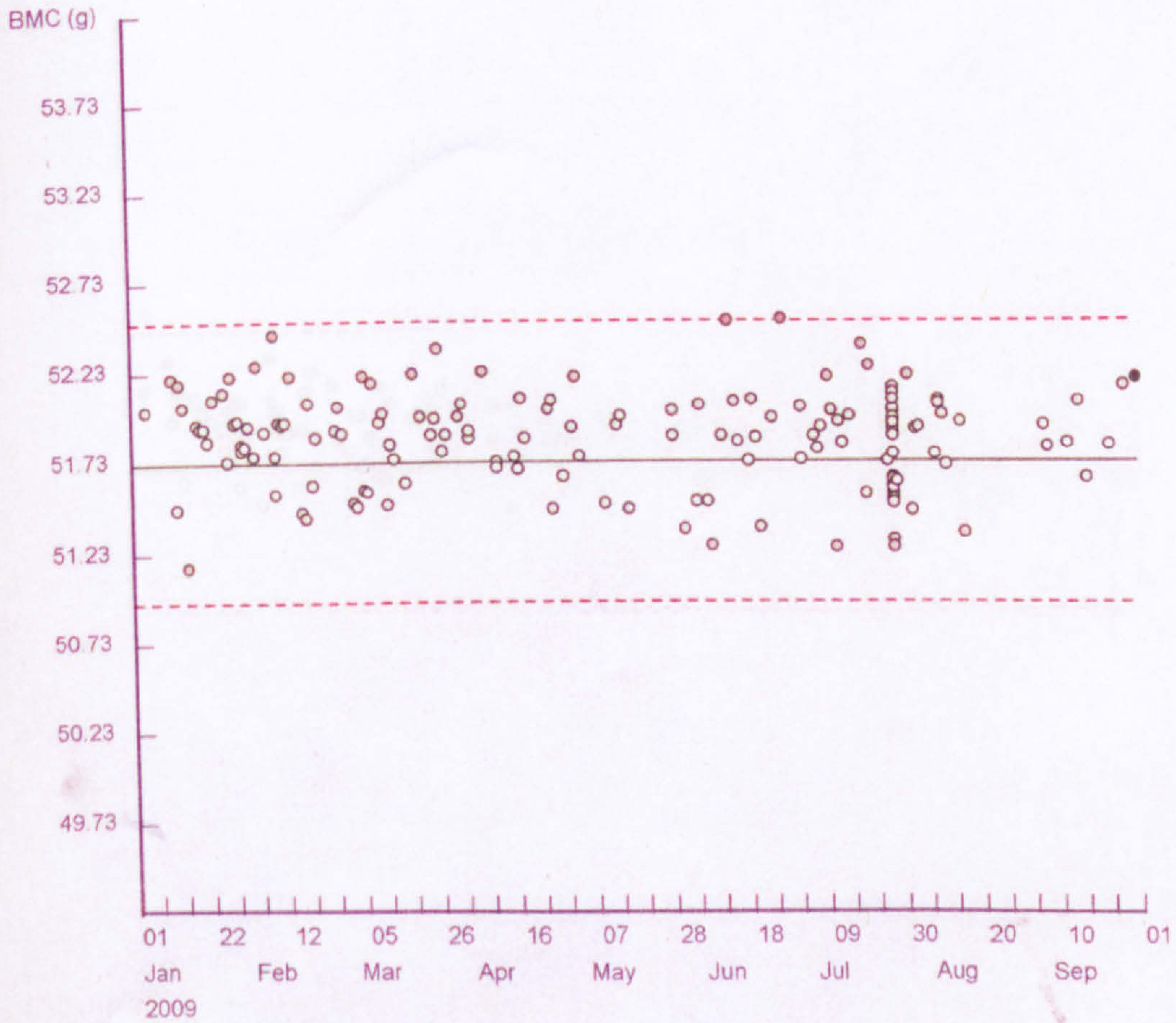
HOLOGIC

Dual-energy X-ray Absorptiometry Calibration Sheets (Chapter 6)



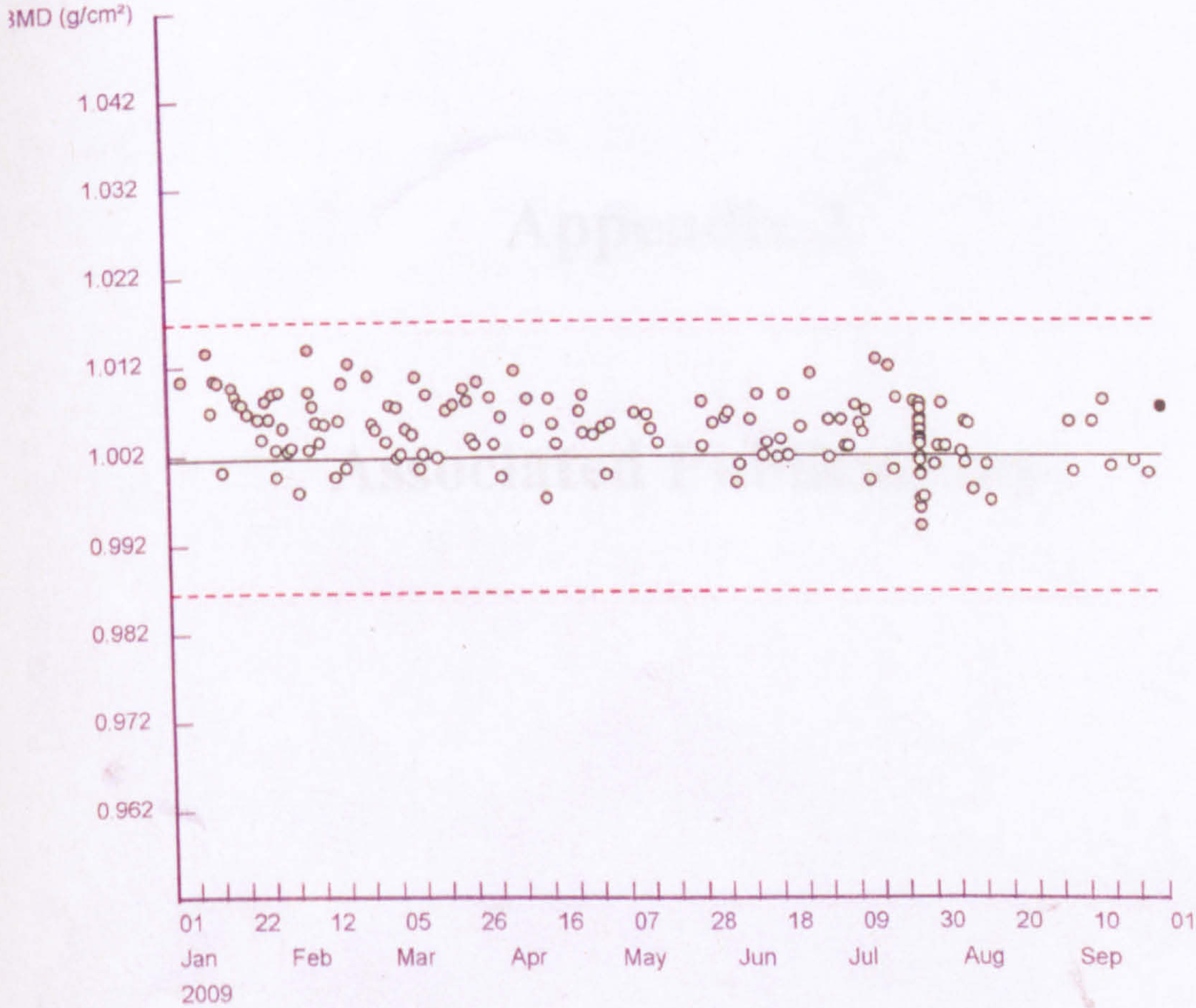
Setup	Reference Values	Plot Statistics
a Lumbar Spine phantom #9837 System S/N: 70719	Limits: ±1.5% of mean Mean: 51.648 (cm²) SD: 0.171 (cm²)	Number of Points: 153 Mean: 51.626 (cm²) SD: 0.247 (cm²) CV: 0.479 %

HOLOGIC



Setup	Reference Values	Plot Statistics
a Lumbar Spine phantom #9837 System S/N: 70719	Limits: ±1.5% of mean Mean: 51.731 (g) SD: 0.267 (g)	Number of Points: 153 Mean: 51.854 (g) SD: 0.264 (g) CV: 0.509 %

HOLOGIC



Setup	Reference Values	Plot Statistics
a Lumbar Spine phantom #9837 System S/N: 70719	Limits: ±1.5% of mean Mean: 1.002 (g/cm²) SD: 0.003 (g/cm²)	Number of Points: 153 Mean: 1.004 (g/cm²) SD: 0.004 (g/cm²) CV: 0.383 %

HOLOGIC

Appendix 2

Associated Publications

Associated Publications

Graves, L., Stratton, G., Ridgers, N. D., Cable, N. T. (2007), Comparison of energy expenditure in adolescents when playing new generation and sedentary computer games: cross sectional study. *British Medical Journal,* **335**, 1282–1284. **(Study 1)**

Graves, L., Stratton, G., Ridgers, N. D., Cable, N. T. (2008). Energy expenditure in adolescents playing new generation computer games. *British Journal of Sports Medicine,* **42**, 592-594. **(Study 1)**

Graves, L. E. F., Ridgers, N. D., Stratton, G. (2008). The contribution of upper limb and total body movement to adolescents' energy expenditure whilst playing Nintendo Wii. *European Journal of Applied Physiology,* 104(4), 617-623. **(Study 2)**

Graves, L. E. F., Ridgers, N. D., Williams, K., Stratton, G., Atkinson, G., Cable, N. T. (in press). The physiological cost and enjoyment of Wii Fit in adolescents, young adults and older adults. *Journal of Physical Activity and Health.* **(Study 3)**

Graves, L. E. F., Ridgers, N. D., Atkinson, G., Stratton, G. (in press). The effect of active video gaming on children's physical activity, behaviour preferences and body composition. *Pediatric Exercise Science*. **(Study 4)**

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